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OPTIMIZATION OF NITROGEN REMOVAL BY RAPID INFILTRATION

VOLUME I. SYSTEM DESCRIPTION AND EVALUATION

by

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16. ABSTRACT

Treatment performance of three rapid infiltration basins receiving primary treated municipal wastewater is evaluated for optimum total nitrogen control using a series of manual operational techniques and by remote control computer operation. Three types of loading sequences were used; flood loading every three and one-half days, flooding daily and sprinkler system loading based on soil moisture sensors and computer analysis and control. The influent and effluent quality variations were increased substantially compared with previous studies. Under optimum conditions, sustained removals above seventy-five percent were achieved with values for individual weeks in the mid-eighty percent range. Nitrogen removals were somewhat less for the automated sprinkler loaded system with a maximum four-week average of sixty-five percent.

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FOREWORD

The U.S. Environmental Protection Agency was established to coordinate the administration of major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

The U.S. Environmental Protection Agency's Office of Research and Development conducts this search through a Nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs including the development and demonstration of soil and other natural systems for the treatment and management of municipal wastewaters.

The rapid infiltration treatment process for land treatment of municipal wastewaters uses the unsaturated soil profile beneath infiltration basins as the treatment media. This project was designed to evaluate the optimization of nitrogen removal in the rapid infiltration system using primary wastewater from the Seventy-Fifth Street Wastewater Treatment Plant in Boulder, Colorado. Two previous studies conducted at the same site evaluated the treatment efficiency for maximum hydraulic loading of applied secondary and primary pretreated municipal wastewater. Results demonstrate that high rate systems can be cost effective alternatives for municipal sewage treatment at sites where conditions are favorable for high hydraulic loading and an excess of seventy percent of total nitrogen removal can be achieved.

This report contributes to the knowledge which is essential for the U.S. Environmental Protection Agency to meet requirements of environmental laws and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

The objective of this research field study was to evaluate operational methods for the optimization of nitrogen removal in the rapid infiltration process. A previous study at the same site had results showing a high degree of biological nitrification but essentially no nitrogen removal through denitrification. This study investigated methods for increasing denitrification. A further objective of the study was to evaluate the efficiency of the removal of other pollutional constituents under the operational conditions necessary for enhanced nitrogen removal.

The rapid infiltration field site consisted of three basins with surface areas of 0.35, 0.19 and 0.22 hectares (0.87, 0.47 and 0.54 acres). Primary effluent from the City of Boulder wastewater treatment plant was applied to the basins utilizing hydraulic loading rates ranging from 4.4 to 42 meters/year (15 to 140 ft/yr). Three types of loading sequences were used; flood loading every three and one-half days, flood loading daily, and sprinkler system loading based on electrical conductivity sensors with computer analysis and control.

The vertical profile of the beds consisted of 0.15 to 0.75 meters (0.5 to 2.5 ft.) of silty sand overlying approximately 2.5 meters (8 ft.) of gravelly sand. Bedrock formed the base of the basins and clay dikes were constructed to act as water barriers on the sides of the basin system. The beds were constructed with underdrain pipes. Direct sampling was accomplished on the influent and effluent flows and flow measurements and balances were made. Pollutional parameter concentrations were measured and removal percentages were calculated.

Total nitrogen removals were increased substantially compared with the previous study. Under optimum conditions, sustained removals above seventy-five percent were achieved with values for individual weeks in the mid eighty percent range. Increased denitrification resulted from maintaining saturated or near saturated soil conditions for long periods, using low infiltration rates and reduced hydraulic loadings. The removal of phosphates was shown to be directly related to a critical phosphorus mass loading of 3.0 Kg/Ha-d (0.3 gm/m^2-d) that represented the mineralization rate for the soil chemistry of the field system. Other operational parameters seemed to have little effect on the phosphorus treatment. Sustained removals greater than ninety-five percent were achieved. BOD and TOC removals were high throughout the study with most BOD values above ninety percent. Reduced hydraulic loading applied with the sprinkler system produced BOD reductions in the range of ninety-nine percent with effluent levels below one mg/l. Coliform percentage removals were high but the three meter depth of soil material utilized in this underdrained system produced effluent coliform concentrations that were great enough that further disinfection may be required in order to meet environmental quality standards.

The computer operated sprinkler loading system was successful in monitoring and controlling the loading that maintained a preset moisture content in the basin soil. BOD and phosphorus removals were excellent with the sprinkler system. Nitrogen removals were slightly less than with the flood loaded system but each successive attempt to improve removal efficiency was successful indicating that further optimization in removal efficiency is possible.

In general, rapid infiltration treatment utilizing optimum conditions for loading, resting and scarification was shown to be a technique that can produce a high quality effluent representing advanced wastewater treatment with a high degree of reliability. For small communities having inexpensive land with proper soil types, it can represent a low cost, low energy consumptive approach to design.

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SECTION 1

INTRODUCTION

The high rate land treatment process utilizing rapid infiltration beds is an economically attractive, low energy consuming process providing a high degree of pollutant removal for municipal wastewaters. In earlier studies (1,2) at the same site and using the same system as this research, it was found that by maximizing infiltration rate, typical loading rates in the range of fifteen to forty-five meters per year (50-150 feet per year) could be achieved and nearly complete (>95%) ammonia conversion to nitrate was accomplished when applying either primary or secondary effluent to a rapid infiltration bed. In that study, high infiltration rates were maintained with frequent resting periods and scarification of the bed surface. The removal of nitrogen from the wastewater resulting from denitrification was relatively low, in the range of fifteen percent.

This research was focused on evaluation of the operational conditions that maximize conversion and removal of the nitrogen forms in the treatment of primary effluent wastewaters. When rapid infiltration beds are designed with direct discharge to the groundwater, nitrogen removal through soil adsorption, biological nitrification and denitrification becomes one of the key parameters in the design and operation of the process. In addition to the determination of the extent of nitrogen removal, the treatment efficiencies for biochemical oxygen demand (BOD), total organic carbon (TOC), suspended solids, coliform bacteria and phosphorus were evaluated under a range of operating conditions.

Three methods of primary wastewater application to the rapid infiltration beds were used in the study. Initially, the beds were flood loaded with approximatily 40 cm (16 in) of primary effluent on three and one-half day intervals. This pattern was followed for the first 78 weeks of the study encompassing the period from December of 1980 through March of 1982. The second loading sequence, which involved only bed 1, utilized a lower loading rate of approximately 5 cm (2 in) of flooding application each day. This was used from April, 1982 through February of 1983. The third mode, the sprinkler distribution system was ready for use on beds 2 and 3 after January, 1983, and it was necessary to discontinue the research operation of bed 1 because the overflow of the sprinkler pumping system was directed to bed 1 and made it impossible to maintain a consistant and measured loading amount. The sprinkler system operated from January through December of 1983, although it was interrupted from March through June due to construction in the treatment plant. In July of 1983, the sensors installed in the soil of the beds were linked to a computer that was programmed to actuate the sprinkler system and maintain a nearly constant, pre-determined

moisture content of the soil at all times. This was done in an effort to maximize the conditions for nitrification and denitrification and optimize the total removal of the nitrogen forms. The computer controlled loadings were used from July, 1983 until December, 1983. The research system was constructed with underdrains so that the influent and effluent parameters could be measured under all operating conditions.

SECTION 2

CONCLUSIONS

Rapid infiltration treatment utilizing flood loading was shown to be capable of removing seventy-five percent of the total nitrogen from wastewater, continuously producing an effluent with a concentration of less than 10 mg/l. In addition, under reduced loading conditions, effluent total nitrogen levels of 7 mg/l, phosphorous of 0.5 mg/l and BOD of 5 mg/l were attained.

Nitrogen removal was enhanced by creating reducing conditions in the near surface soil system. Maintaining a saturated or near saturated soil moisture condition with long periods of continuous flooding of the basins produced the highest nitrogen reductions. In addition, it was found that low infiltration rates improved removals by extending the periods of saturation of the upper portion of the soil. Lowering the mass loading rate and the hydraulic loading of the system reduced the ammonia leakage from the system.

It is possible to remotely control the operation of a rapid infiltration system using transducers in the field. The servo control system utilized was effective in maintaining nitrogen removal efficiencies as well as diagnosing system problems permitting rapid repair of field problems. One area for further development with the computer operation is improving the sensors used for obtaining reliable measurement of field moisture conditions.

The maximum phosphorus removal for this site was found to be 3.0 Kg/Ha-d (0.3 gm/m^2-d). It was concluded that this value represented the mineralization rate for the soils employed in the study. When loadings exceeded this level, the mineralization reaction was not capable of regenerating the sites for the phosphorus adsorption reaction at a fast enough rate to maintain a balance between the two reactions and the treatment efficiency declined rapidly.

BOD reductions were high for all of the loading conditions studied. A large portion of the BOD was removed in the solids mat produced at the surface of the beds by the accumulation of the solids present in the primary effluent. BOD removals were found to be improved at lower hydraulic loading rates.

The rapid infiltration basins provided major reductions in coliform bacteria densities. However, with the three meter depth of earth materials utilized in the underdrained system of this study, the removals were not sufficient to meet some environmental water quality standards and disinfection processes may be a required part of the process for discharging of the effluent into a stream.

Each of the three rapid infiltration beds had an approximately three meter (10 foot) depth of soil materials. Two of the beds had approximately 15 cm (6 in) top soil cover over the coarse aluvial material while the other bed had approximately 75 cm (30 in) of top soil cover. Since all three beds gave very similar results for the pollutant removals that were evaluated, it is concluded that a major portion of the removals occurred in the top 15 cm (6 in) of the beds.

Operational problems with the flood loaded beds were minimal throughout the year. The use of primary effluent did not create odor problems. Operation of the sprinkler loading system was not possible when the ambient air and soil temperature dropped below freezing.

SECTION 3

RECOMMENDATIONS

From the observation made during the course of this study, the following observations seem appropriate.

The nitrogen and phosphorus removal mechanisms in land treatmemt systems are dependent on the adsorption capacity of the soil for these constituents and by the regeneration rate of the sorption sites by biological reactions and chemical precipitation reactions. Studies relating the properties of different soils with removal effectiveness would provide a greater understanding of the mechanisms of the treatment process and provide direction for the selection of the land treatment location for the design engineer.

Nitrogen removal requires oxidation of ammonical nitrogen and reduction of nitrate nitrogen to gaseous forms. It has been shown that nitrification is not difficult to maintain when sufficient oxygen is available even at near $0^{o}C$ soil temperatures. Removal effectiveness has, on the other hand, been shown to be related to soil moisture conditions which produce reducing environments. Further development of operational parameters for creating optimal moisture conditions which will reduce the nitrate while maintaining sufficient oxygen to nitrify the ammoniacal nitrogen would be useful.

Electrical conductivity of the bulk soil-water system can be used as an assessment of soil moisture conditions. Due to variations in the electrical conductivity of the applied water (precipitation versus wastewater), precise control of soil moisture conditions was not possible. It would be desirable to develop instrumentation which would measure soil moisture or air filled porosity without the influence of other environmental parameters. Adequate instrumentation would permit further development of criteria for optimum nitrogen removal.

Most rapid infiltration systems have been designed with the concept that the effluent percolates to a groundwater aquifer. The alternate system utilizing beds designed with underdrains and discharge to a surface stream, such as the system used in this research project, has been shown to be a highly effective means of providing advanced wastewater treatment with a high degree of reliability while requiring low energy consumption and ease of operation. The system would be similar in some ways to the intermittent sand filters presently in use except that the soil materials would provide for nitrogen removal by denitrification and phosphorus removal by adsorption and precipitation. The underdrained system concept should be developed further as a contained system for small communities or cluster home developments.

SECTION 4

EXPERIMENTAL FACILITIES AND PROCEDURES

The demonstration rapid infiltration system at Boulder, Colorado was constructed in 1975 and was used in previous studies (1,2) to establish the adequacy of such a system as a means of providing tertiary nitrification for the wastewater of the City of Boulder. Wastewater loadings were initiated in the present study in December of 1980 and field evaluations were continued until December of 1983. One objective of this research was to optimize the operating conditions of the beds for the removal of nitrogen through the mechanism of biological nitrification and denitrification occurring simultaneously as the wastewater passed through the soil material. Another objective was to evaluate the performance of the rapid infiltration system for the removal of other pollutants including biochemical oxygen demand (BOD), total organic carbon (TOC), suspended solids, coliform bacteria and phosphorous. In addition, the change in cation concentrations in the wastewater including calcium, magnesium and sodium were monitored along with changes in pH. The study was accomplished using several loading rates for both flood loading and computer actuated sprinkler loading modes.

SITE DESCRIPTION AND SYSTEM OPERATION

The rapid infiltration beds of this research were situated directly east of the wastewater treatment plant in Boulder, Colorado, on the south bank of Boulder Creek. The site consisted of three basins, which were designated one, two, and three moving from south to north. The configuration of the beds is shown in Figure 1. The earth materials in the beds were approximately three meters (10 ft) deep and the base material was an impermeable shale strata. Earth berms, approximately 0.8 meters (2.5 ft) high, separated the basins, while a clay dike surrounding the entire basin area isolated the system from local groundwater. The Boulder treatment site, shown diagrammatically in Figure 2, supplied the primary effluent applied to the infiltration basins with a model 71011 Worthington pump through a 0.35 meter (14 in) low presure pipe during the entire study.

After the wastewater passed through the soil materials in the beds, it was collected in an underdrain system made up of two perforated 18 cm (7 in) diameter pipes running the length of each bed at a depth of 2.5 to 3.2 m (8 to 10 ft), just above the shale layer at the bottom of the beds. The underdrain pipes emptied into a central effluent sampling manhole. From there, the effluent was pumped to Boulder Creek. The lines from each of the beds had a V-notched weir installed in the individual channels in the effluent sampling manhole and a horizontal plate was installed in such a

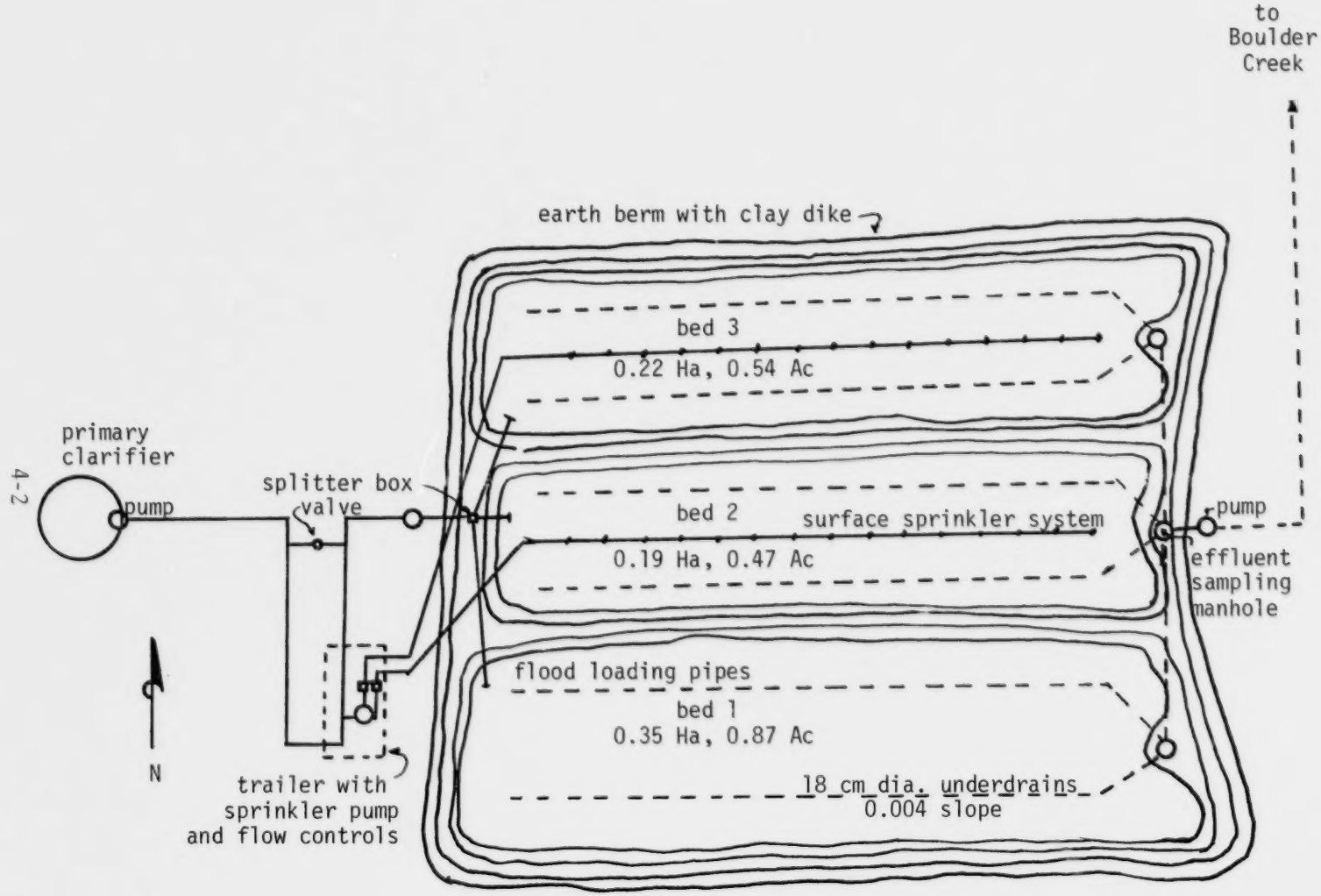

Figure 1. The rapid infiltration system layout.

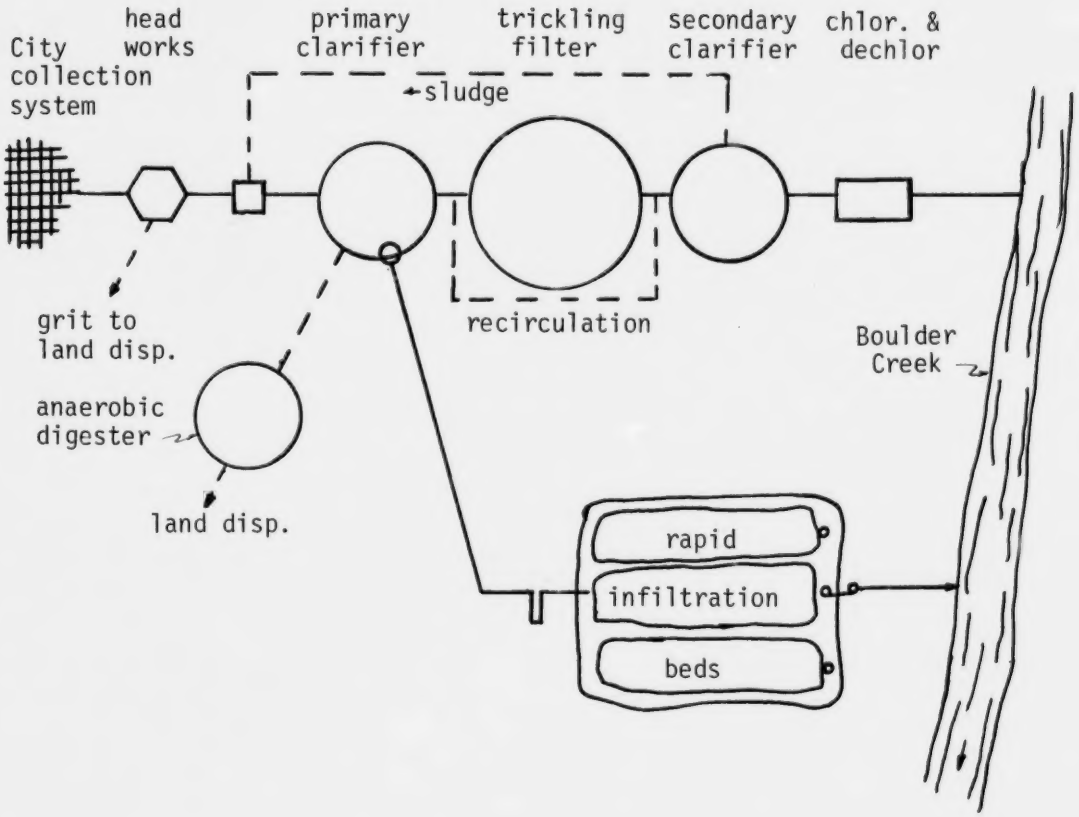

Figure 2. Schematic of the Boulder wastewater treatment plant.

position that a point gauge could be used to measure water depth in the upstream pool and flow rates were calculated using this arrangement. Effluent samples for chemical analysis were taken in the flow channels of this manhole. Influent samples for the rapid infiltration beds were taken from the splitter box for the flood loading conditions or from beakers placed on the beds during sprinkler loading.

For the first two years of the study, the influent pipe lead directly to an in-line, totalizing, propeller flow meter and then to a distribution-splitter box. Lift gates were used to divert the flow to bed 1, bed 2 or bed 3 during flood loadings. The basins were operated in a cyclic pattern of loading and resting. The first phase of the study lasted for 68 weeks, from December 1980 until March of 1982. Initially a 23-week sequence was studied and this was followed by a series of 6 to 8 week loadings separated by 3 to 4 week resting periods. During this time all three beds were flood loaded with approximately 40 cm (16 in) of wastewater on 3.5 day intervals. Bed 1 was loaded at 7 AM on Monday and 7 PM on Thursday of each of the weeks of loading. Bed 2 was loaded at 7 AM on Tuesday and 7 PM on Fridays and bed 3 was loaded at 7 AM on Wednesday and 7 PM on Saturdays. Scarification of the beds was done during weeks 27, 33 and 49 with a tractor and disk. The second phase of the flood loading was conducted on bed one from April, 1982 to February, 1983. During this period of time the bed was loaded with approximately 5 cm (2 in) of wastewater each day of the week at 8 AM. Scarification of the beds was done during weeks 70 and 111.

During the final year of the study a fixed sprinkler distribution system was installed on beds 2 and 3. To obtain sufficient operating pressure for the sprinklers, a 6.5 m (20 ft) section of pipe was removed, reducers were attached to each end of the pipe and a 15 cm (6 in) diameter PVC pipe was installed in a "U" shape, through a control trailer and back to the original pipe. The primary purpose of the sprinkler system was to distribute the wastewater over the entire basin without requiring surface flooding.

The sprinkler system consisted of a network of 10 cm (4 in) diameter aluminum irrigation pipes with risers installed at 6.2 m (20 ft) intervals. Nelson F33AS impact sprinkler nozzles were installed at the top of the risers with each nozzle having a 0.43 cm (11/64 in) orifice. There were 13 nozzles per bed designed to apply a total of 0.0045 m^3/s (70 gpm) at 276 kPa (40 psi). The pipeline from the primary clarifier to the infiltration beds was modified so that it passed through a trailer in an inverted "U" shaped loop. A tee was installed in the pipe so that flow could be directed to the flood loading bed or it could be diverted to a separate pump and valving system that would allow the sprinkler system to be operated. Each of the plots was controlled by pneumatically operated valves with pneumatic positioners as shown diagrammatically in Figure 3. The switches shown diagrammatically in Figure 3 were operated using a remote computer interface shown in Figure 4, which in turn was controlled by a computer located in RSKERL, Ada, Oklahoma shown in Figure 5. The computer was used to control the operation of the system by sensing the electrical conductivity of the soil as an assessment of the water content. The measured electrical conductivity was modified to correct for temperature based on temperature measurements made in the field. Each plot contained three Martek SCT soil conductivity transducers installed

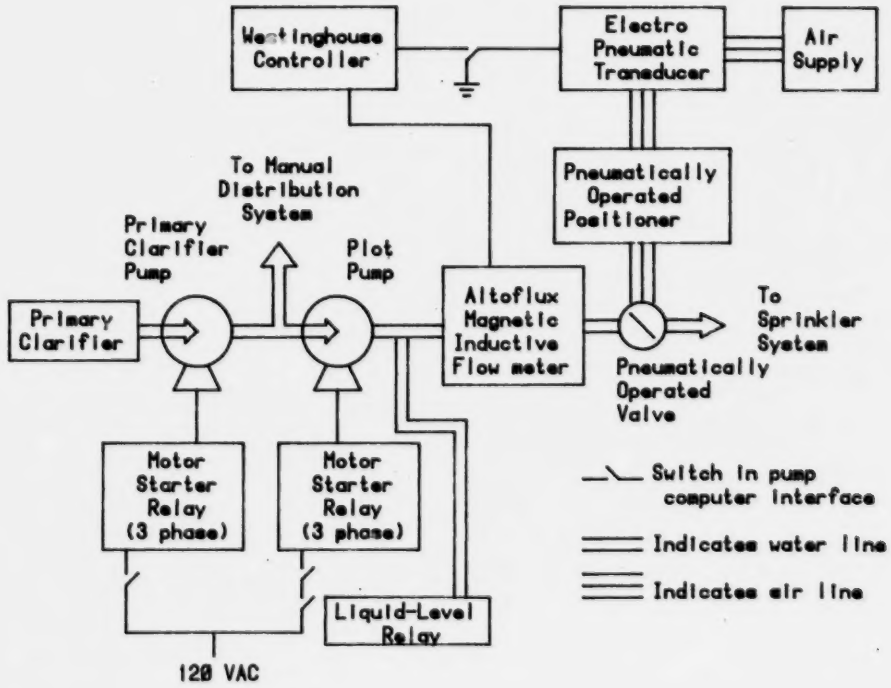

Figure 3. Schematic of pneumatically operated valves with pneumatic positioners.

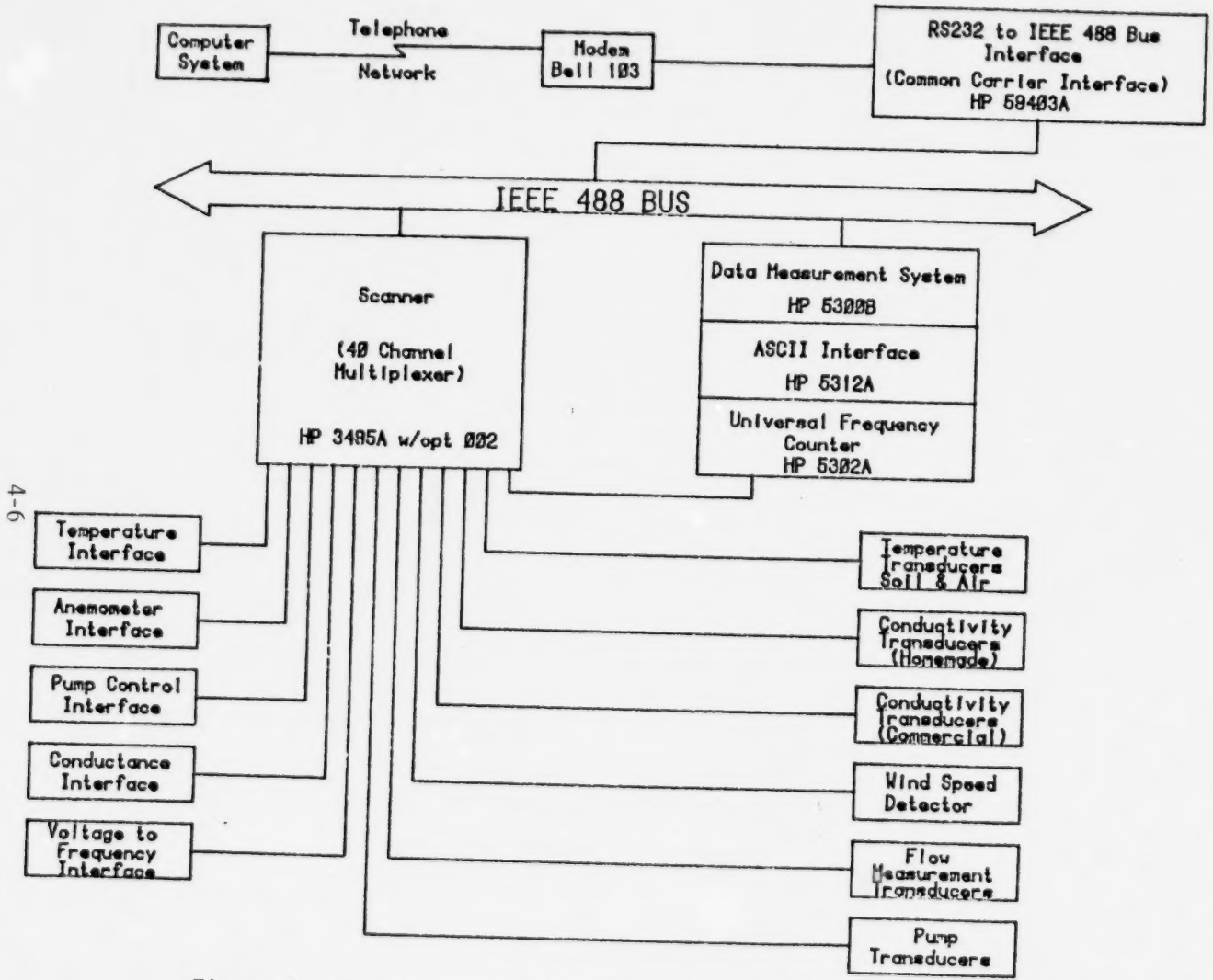

Figure 4. Remote computer interface data collection system at Boulder.

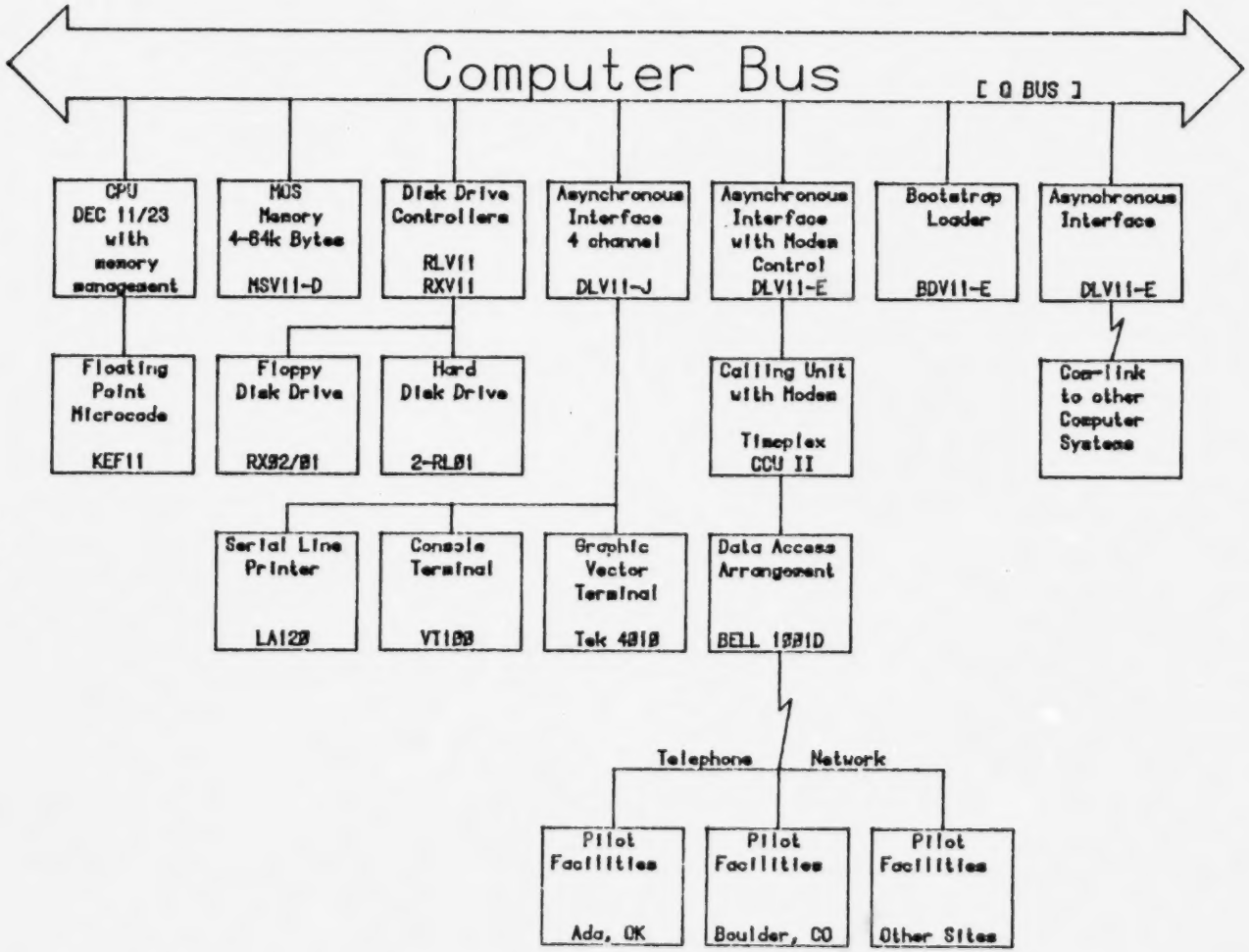

Figure 5. Schematic of computer system components at RSKERL.

5 cm (2 in) below the surface and three sets of stainless steel rods for assessing the electrical conductivity of the soil along with National Semiconductor LM 335 temperature transducer placed at the same location. There was also an additional temperature transducer placed 30 cm (1 ft) below the surface in each plot and one temperature transducer to measure ambient air temperature. Based on the corrected electrical conductivity measurements, the computer operated the pumps and valves attempting to maintain a constant electrical conductivity of the soil.

The computer allowed water application only when the air temperature was above $-5^{o}C$, and the wind speed was below 15 m/s (35 mi/hr). This prevented excessive ice buildups and excessive wind drift of the wastewater. Instantaneous flow rates were measured and used along with the internal clock of the computer to calculate the average daily flow for the system.

The two mode loading process is shown in Figure 1. The photographs of Figures 6 through 10 have been included to provide a visual impression of the system. The loading patterns are summarized in Table 1. The loading rate for the 3.5 day pattern averaged 123 ft/yr. based on the weeks that loading actually occurred. Resting of the beds was necessary and this occupied 28 percent of the weeks of this portion of the study. The overall average loading rate over time including resting periods is given in the table. No intentional resting periods were utilized with the 1 day or sprinkler system patterns. Downtime periods caused be construction in the wastewater treatment plant were not included in the calculation of loading rate. Loading values for each week of the study are given in the appendix.

TABLE 1. LOADING DEPTHS

	flood (3 1/2 day)	flood (1 day)	sprinkler
loading rate, inc. resting cm/d	7.42	4.67	3.84
ft/yr	88.6	56.0	46.0
$gal/d\text{-}ft^2$	1.8	1.15	0.95
% of permeability	15	9	8

SOIL ANALYSIS

The rapid infiltration site was located in the Piedmont section of Boulder County. The surface soils in this section consist of unconsolidated deposits of Quaternary age.(3) These deposits were composed of loose sand, loose gravel, and clayey sand underlain by bedrock of oceanic origin. The soils of the Piedmont section have been classified into several associations, with the soil at the rapid infiltration site falling in the Niwot-Loveland-Calkins association. Soil samples were taken to the full depth of each of the beds after they had been used for treating wastewater for several years. An additional sample was taken in the soil outside the beds in an area where the surface soil layer had been removed and this represented the earth

Figure 6. Flood loaded beds.

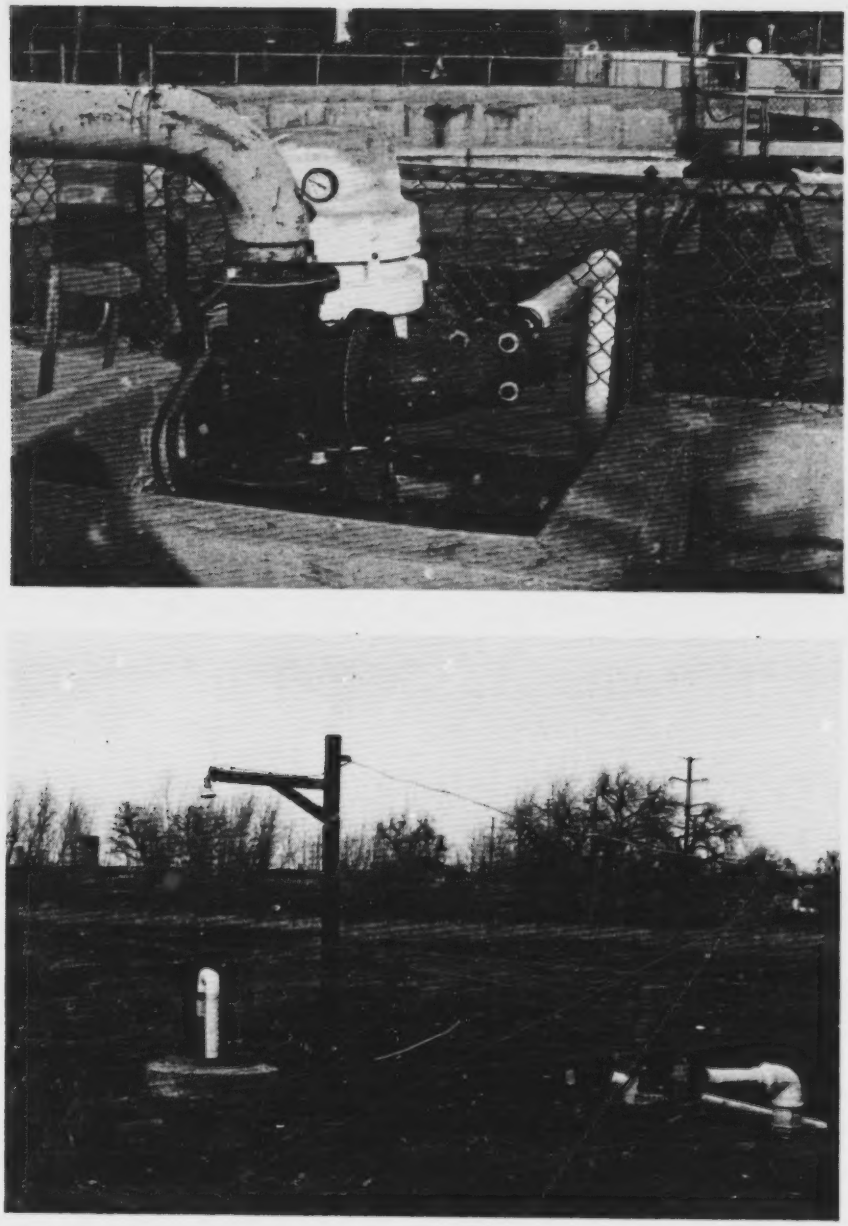

Figure 7. Influent pump (top), effluent pump and sampling manhole (bottom).

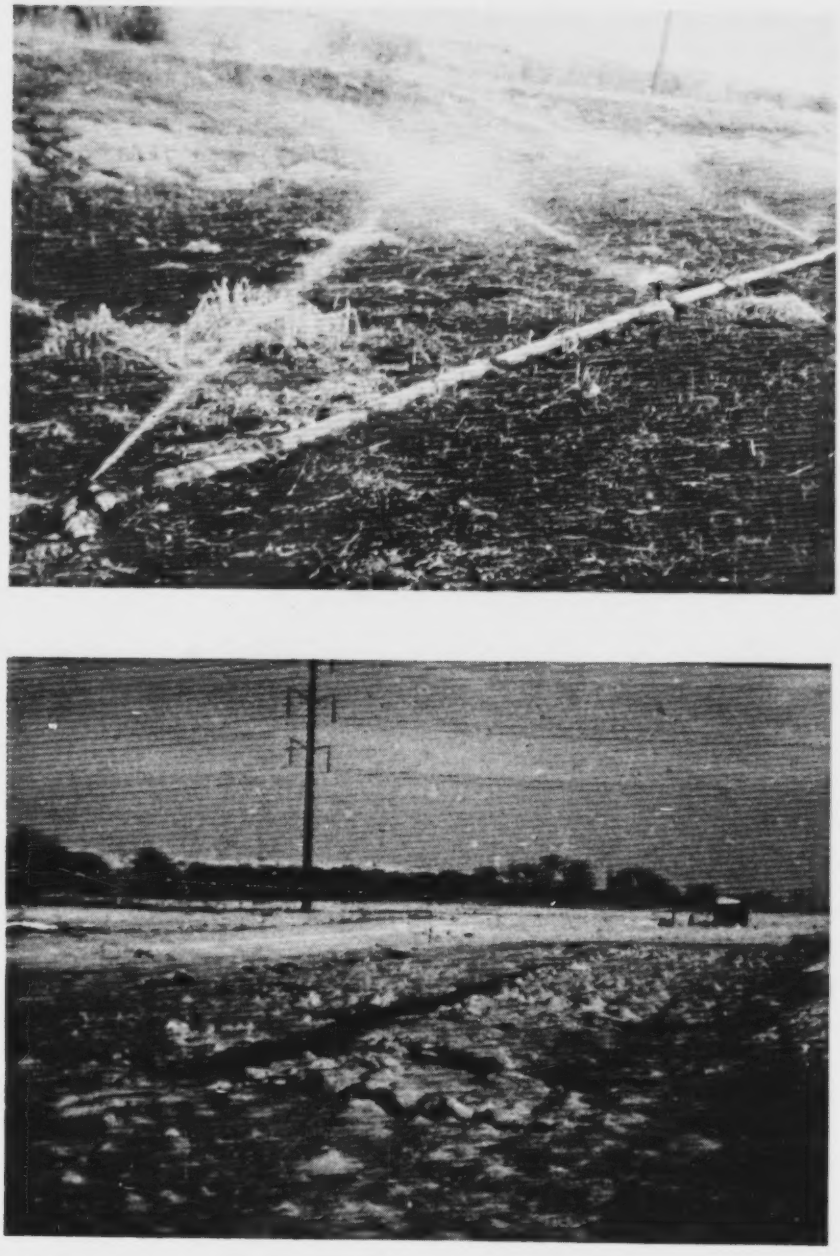

Figure 8. Sprinkler system on beds, summer (top), winter (bottom).

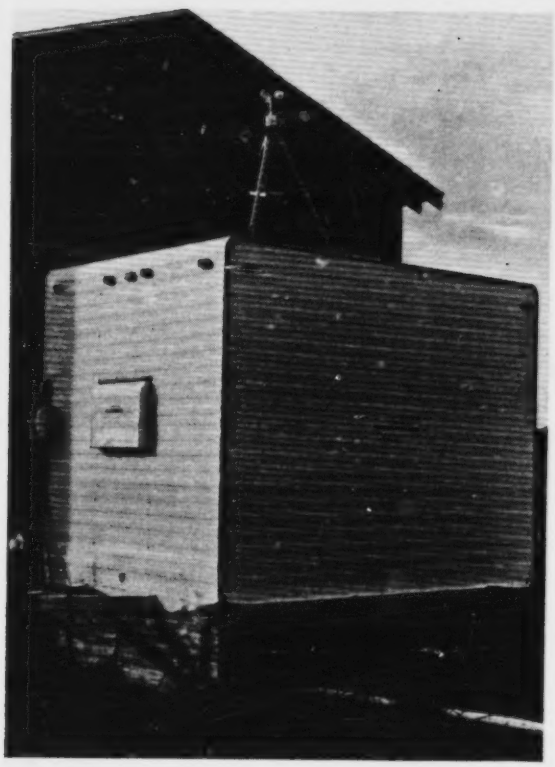

Figure 9. Sprinkler end cap (top), trailer (left), soil sensors (right).

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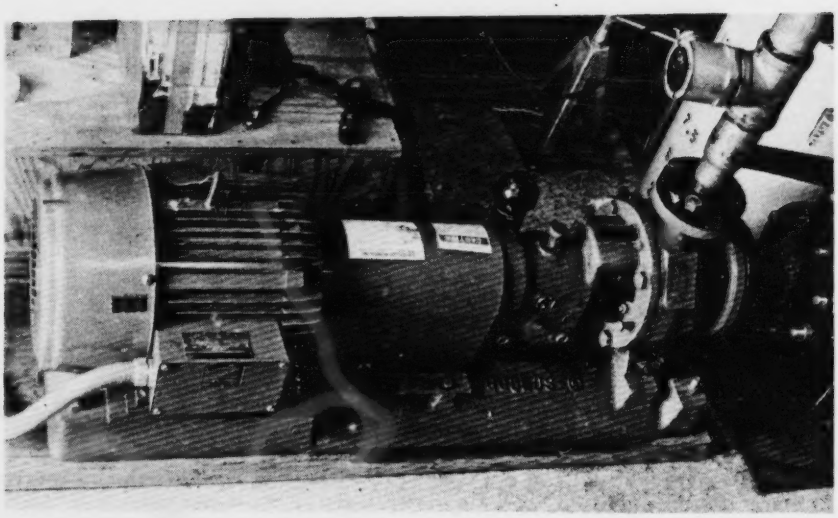

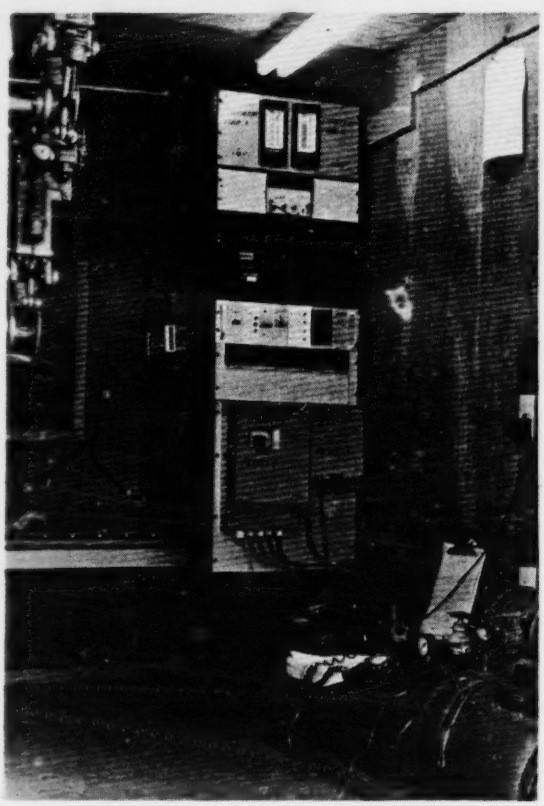

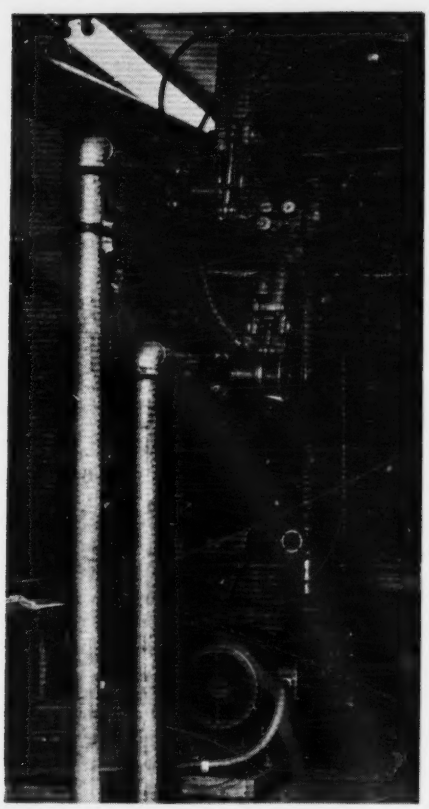

Figure 10. Sprinkler pump, control panel (left), flow controllers (right).

material that had not been subject to wastewater loading. A tabulation of the grain size analysis of the soil at several boring depths as well as the boring logs are shown in Table 2, as recorded by Chen (4). Each of the beds had approximately 75 cm (2.5 feet) of finer textured material at the surface overlying coarse sand and gravel in the lower portion of the system. Prior to this study, 60 cm (2 ft) of the finer material was removed from beds 2 and 3 so that 15cm (0.5 ft) of finer textured materials remained. All of the beds had twelve or more percent clay and two and one-half percent or more organic matter in the surface layer. The chemistry of the soils is shown in Tables 3 and 4.

SAMPLING METHODS

Influent sampling for the flood loading mode utilized an Isco automatic sampler, model 1390, which took 200 ml of the flow every one-half hour during the approximately seventeen hour loading period. Every second volume was released into a cup containing sulfuric acid while the other portions were unacidified. At the end of the loading period, compositing produced an acidified and an unacidified aliquot for each loading. One loading per week was analysed for each of the basins. Influent sampling for the sprinkler loading operation involved placing two beakers on the surface of the beds in the spray pattern, one with acid added, and collecting two volumes. This was also done once per week. All acidified samples had a pH of less than 2.

Two types of effluent samples were taken, acidified and unacidified. All volumes were taken at the outlet streams of the individual beds in the effluent manhole. For the flood loading sequence, grab aliquots were obtained at seven hours after the loading was begun and this represented a time near the effluent flow peak and they were not acidified. The acidified volumes were used for the nitrogen analyses and it was necessary to obtain a series of samples after each loading so that a flow weighted mean could be established. Acidified samples and effluent flow measurements were taken at 3, 7, 10, 24, 34, 48 and 72 hours after loading was initiated. The acidified aliquots were used for the analysis of ammonia, total Kjeldahl nitrogen, nitrate, phosphorus and TOC. The unacidified volumes were for pH, BOD and suspended solids analyses. Special grab samples of influent and effluent flows were obtained using sterilized bottles for the coliform tests and using nitric acid acidified bottles for the calcium, magnesiun and sodium series.

CHEMICAL ANALYSES

The chemical analyses for total Kjeldahl nitrogen were accomplished using procedures detailed in Section 421 of Standard Methods (5) from the beginning of the project until Febuary of 1982. A 250 ml sample was carried through the digestion and distillation steps. Final TKN and ammonia nitrogen measurements were accomplished with an Orion Research Electrode, model 95-10. After February, 1982, a Technicon Autoanalyzer II with ammonia cartridge was used for ammonia and TKN analysis using methods from the instrument manual. TKN samples were first digested in a Techne model DG-1 block digester prior to analysis. Nitrate-nitrite nitrogen determinations were made using the

TABLE 2. SOIL ANALYSIS (percent dry weight)

Depth Feet	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay	Org. Mat.
Grain size	>2 mm	1-2 mm	.5-1 mm	.25-.5 mm	.1-.2 mm	.05-.1 mm		<.02 mm	
Bed 1									
0-.25	5.3	9.8	10.9	10.1	18.2	10.4	16.3	20.0	3.7
1	12.9	5.6	8.5	9.4	19.0	9.0	18.3	18.3	3.7
2.5	11.1	4.6	11.6	15.0	20.2	9.4	12.7	15.4	2.9
5	74.4	9.3	6.4	3.1	2.9	1.3	0.8	1.8	0.3
8	62.8	14.8	10.8	4.6	3.6	1.2	1.1	1.1	0.3
Bed 2									
0-.25	13.9	7.2	24.2	15.3	14.0	4.8	8.6	12.2	2.5
1	56.1	6.6	8.1	9.2	10.3	3.2	5.2	1.3	0.3
3	67.2	7.9	12.1	7.4	3.2	0.9	0.3	1.0	0.2
5	10.6	32.6	27.7	11.3	8.4	2.2	6.3	0.9	0.1
Bed 3									
0-.25	19.7	6.7	10.7	9.3	17.7	7.1	16.8	12.0	2.6
1	59.3	16.3	13.3	4.1	2.6	1.0	2.1	1.3	0.3
2	50.9	17.0	15.7	5.8	5.0	1.8	2.4	1.4	0.3
5	41.5	23.0	16.5	8.1	6.7	1.3	2.3	0.6	0.1
8	77.4	5.5	8.3	3.6	2.7	0.6	1.3	0.6	0.1
Outside of Bed 1 (control)									
0-.25	71.4	7.8	4.5	2.3	4.5	2.1	4.0	3.4	1.0
1	68.1	9.8	7.3	3.5	3.9	1.6	2.0	3.0	0.5
2.5	60.5	9.7	8.6	5.5	7.8	2.8	2.3	2.8	0.2
5	68.8	6.9	7.6	3.5	5.2	2.7	3.2	2.1	0.2
8	38.8	7.8	11.3	9.5	16.5	6.8	4.3	5.0	0.1

Hole Boring logs (4)

Bed 1) 0-2.7 ft (SC) sand-clayey, 2.7-12 ft (SM) silty, gravely sand, 12+ ft bedrock, water table at 7 ft below surface.

Bed 2) 0-0.5 ft (SC) sand-clayey, 0.5-5 ft (SM) silty, gravely sand, 5-7.5 ft (SP) clean sand, 7.5+ ft bed rock, water table 7 ft below surface.

Bed 3) 0-0.5 ft (SC) sand-clayey, 0.5-3 ft(SM) silty, gravely sand, 3-7 ft (SP) clean sand, 7-11 ft (SM) silty, gravely sand, 11+ ft bedrock, water table 7 ft below surface.
Outside Bed 1) 0-1.8 ft (SC) sand-clayey, 1.6-14 ft (SM) silty, gravely sand, 14+ ft bedrock, water table at 5 ft below surface.

TABLE 3. SOIL CHEMICAL PROPERTIES

Depth Feet	CEC meq 100g	Fixed NH4-N ppm	Moisture content %	2MKCl extract NH4-N ppm	2MKCl extract NO3-N ppm	water extract NH4-N ppm	water extract NO3-N ppm
Bed 1							
0-.25	24.2	22	23.9	172	1	61	<1
1	21.4		23.5	8	1	3	2
2.5	16.4		22.8	9	<1	5	<1
5	2.9		8.9	8	<1	9	<1
8	2.6	10	15.9	3	<1	3	<1
Bed 2							
0-.25	14.8	37	29.4	193	<1	23	<1
1	2.6		8.2	11	2	11	2
3	2.4		6.9	9	1	10	<1
5	2.1		10.2	13	2	10	2
Bed 3							
0-.25	14.8	42	26.7	129	2	22	1
1	1.9		5.8	17	1	12	<1
2	2.6		7.4	11	1	10	1
5	1.9		6.2	3	2	3	2
8	3.1		16.9	14	<1	11	<1
Outside of Bed 1 (control)							
0-.25	11.0	10	8.2	1	2	1	2
1	5.5		6.5	2	4	1	4
2.5	4.3		5.7	1	5	2	4
5	3.6		5.3	1	1	1	2
8	4.3		13.9	2	1	2	1

TABLE 4. SOIL CHEMICAL ANALYSIS

A sample taken at a depth of 1.3 ft (0.4 m) in Bed 1 gave the following analysis:

Type of soil-sandy loam (international classification of silty sand

pH	5.4
Conductivity	0.4
Extractable Phosphorous ppm	28.0
Extractable K ppm	103.0
Extractable Zn ppm	2.8
Extractable Al ppm	2.0
Extractable Fe ppm	249.0
Extractable Ca ppm	820.0
Extractable Mn ppm	17.8
Extractable Cu ppm	7.8
Extractable F ppm	0.8
Total Fe percent	3.07
Total Al percent	6.85
Total Ca percent	1.29

Technicon Autoanalyzer II with the cadmium reduction method described in Section 605 of Standard Methods (5).

Total phosphorus analyses were performed by the colorimetric method outlined in Section 365.3 of Methods for Chemical Analysis of Water and Wastes (6). Light absorbance was measured with a Bausch and Lomb Spectronic 70 instrument. Total organic carbon was determined using a Beckman model 915B total organic carbon analyzer. Five replicate volumes of 45 microliters each were analyzed for each influent and effluent sample.

The unacidified samples were stored at $4^{o}C$ when necessary prior to analysis. The analyses for BOD and pH were made when the samples arrived in the laboratory and usually no storage was necessary. The five day biochemical oxygen demand test (BOD) was determined according to section 507 of Standard Methods (5). The iodimetric procedure with azide modification was used to calibrate the Yellow Springs model 54A oxygen meter and the meter was used to measure the dissolved oxygen levels in the test bottles. The dilution water was aerated for 0.5 hour and stored in the BOD box at $20^{o}C$ prior to use. The dilution water was seeded with one ml of settled sewage for each two liters of water. An Orion model 399A ionalyzer was used to determine the pH of the samples. Suspended solids were determined as outlined in section 160.7 of Methods for Chemical Analysis of Water and Wastes (6). A sample volume of 100 ml was used for influents and 200 ml for effluents.

The analyses for total and fecal coliform determinations were done as soon as the samples reached the laboratory using the membrane filter technique as given in sections 909A and 909C of Standard Methods (5). However, the phosphate buffer step was eliminated. Three dilutions were made of the influent and effluent samples and triplicates were run on each dilution.

The measurements for calcium, magnesium and sodium were made using the instructions for the atomic absorption spectrophotometer, Model IL 151/251.

LABORATORY QUALITY ASSURANCE PROGRAM

Laboratory quality control was accomplished using duplicates for all analyses with spikes and blanks tested with a frequency of one or more of each with every ten samples analysed. Laboratory quality water from a Milli-Q system and reagent grade chemicals were used in the preparation of all standards, stock reagents, dilutions and blanks. Spiked samples and blanks were run with all analyses except pH, suspended solids and coliforms. Statistical analysis of the spiked samples was used to determine the accuracy of each test while statistical analysis of the replicates determined the precision.

For each set of replicate samples the percent variation from the mean of the two values was calculated, based on the following:

$$\% \text{ variation} = 100 \text{ (ave. conc. - individual conc.)/ave. conc.}$$

The results of all the (n) number of samples for the same chemical parameter were ranked and ordered using the following:

$$\% \; [<\% \text{ variation}] = 100 \; \text{rank}/(n + 1)$$

and this was plotted on probability paper as a function of % variation. A typical plot is shown in figure 11. The standard deviation of the percent variation of the data set was calculted from:

$$\text{std. div.} = [(X-\bar{X})/(N+1)]^{0.5}$$

with X = the individual value, $\overline{X}$ = the ave. value of all samples, and N the total number of samples.

The percent variation distribution of replicants was determined for influent and effluent samples for TKN, ammonia, nitrate, BOD, TOC, suspended solids, phosphorus, fecal and total coliform analyses. The percent recovery distribution of spiked samples was determined for influent and effluent samples for phosphorus, BOD and TOC analyses. For the nitrogen analyses, spike recoveries were determined for only effluent samples. The boundaries for acceptable tests were set at a value of two standard diviations from the mean and the dashed lines on the figure at 2.28 percent and 97.72 percent represent these points. The intersection of the line of fit for the data points and the dashed lines were the limiting values for duplicate variation and greater values occuring in a test required that the analyses be repeated. The standard deviation of replicates and the mean and standard deviation of spike recoveries are shown in Table 5. The variation of the mean value for replicates was zero.

REMOTE DATA COLLECTION QUALITY ASSURANCE

Several internal functions of the data collection system were monitored throughout the duration of the project. The internal monitoring permitted evaluating the overall performance of the measurement system but did not give any indication of the accuracy of individual transducers. Volume II presents a summary of the data collected along with a statistical analysis. As shown in figure 4, there are several points in the measurement system that errors could occur. In an attempt to determine the magnitude of these errors several internal standards were monitored throughout the experiment. A discussion of the errors are included in Volume II of this report.

MASS FLOW CALCULATIONS FOR NITROGEN

To determine the nitrogen removal efficiency of the rapid infiltration system in the flood loading mode, it was necessary to make flow and concentration determinations for each of the nitrogen forms several times during the loading cycle. The influent was loaded at a constant rate of 22.7 liters per second and an automatic sampler was used to produce a composite sample that was representative of the average influent concentration for each

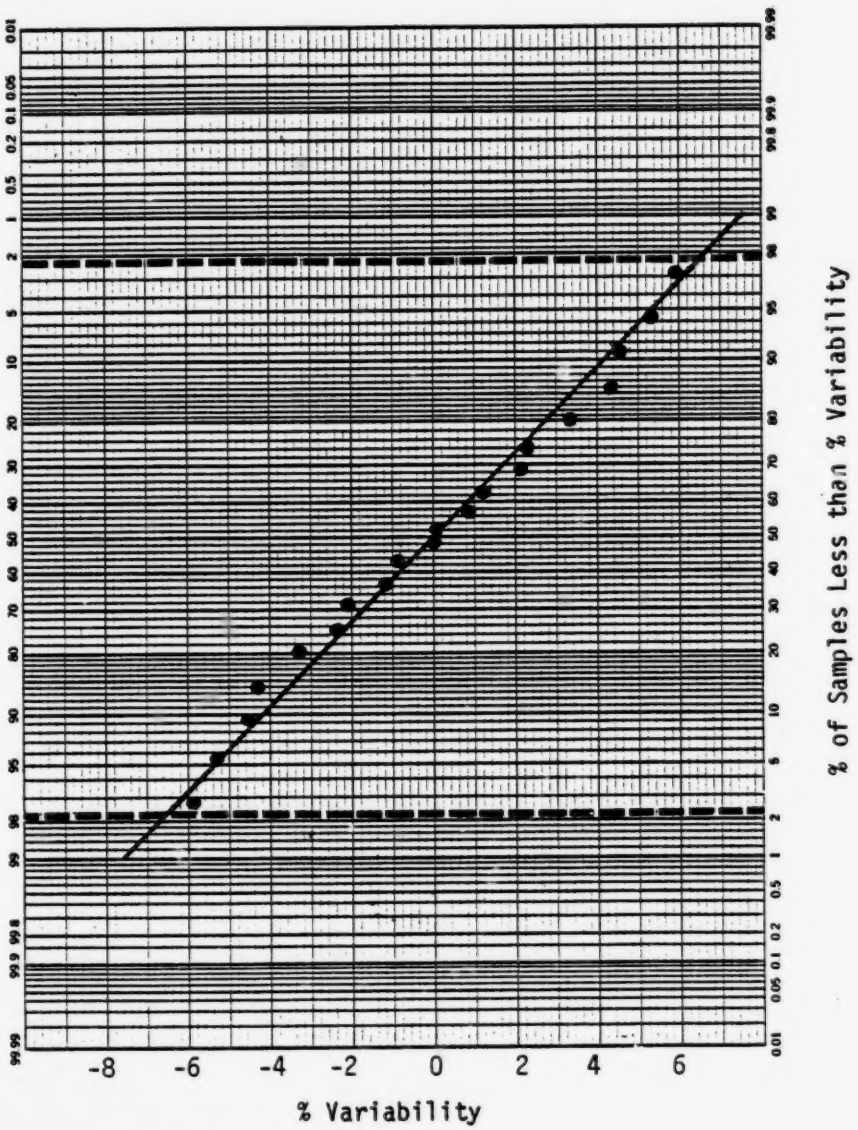

Figure 11. Distribution of % variation of influent phosphorus duplicates.

TABLE 5. STANDARD DIVIATIONS OF CHEMICAL ANALYSES

Replicates		Spiked samples		
Sample Analysed	Standard diviation	Sample Analysed	Mean	Standard diviation
Inf. TKN	4.5%			
Eff. TKN	8.2%	Eff. TKN	105.0%	22.8%
Inf. Ammonia	1.2%			
Eff. Ammonia	1.2%	Eff. Ammonia	97.6%	4.3%
Inf. Nitrate	3.0%			
Eff. Nitrate	0.9%	Eff. Nitrate	104.6%	4.2%
Inf. P	3.2%	Inf. P	107.5%	28.4%
Eff. P	12.7%	Eff. P	150.2%	38.2%
Inf. BOD	1.3%	Inf. BOD	144.0%	30.6%
Eff. BOD	2.0%	Eff. BOD	135.5%	26.8%
Inf. TOC	5.0%	Inf. TOC	98.3%	6.2%
Eff. TOC	16.1%	Eff. TOC	101.9%	3.3%
Inf. Tot. Coli.	15.1%			
Eff. Tot. Coli.	24.8%			
Inf. Fec. Coli.	16.6%			
Eff. Fec. Coli.	13.9%			
Inf. Sus. Sol.	10.0%			
Eff. Sus. Sol.	34.6%			

of the nitrogen forms. The effluent pattern was not a constant flow and the concentrations of the nitrogen forms changed throughout the three and one-half days between loading cycles. This is shown in Figure 12, for week 39 of the study. Effluent flow weighted concentrations were calculated from the data that was obtained by sampling at several intervals, at 3, 7, 12, 24, 34, 48, 60, and 72 hours after the initiation of loading. Although TKN values are shown in the figure, ammonia nitrogen concentration measurements were also made on each sample and the mass of each nitrogen form was calculated. First the outflow curve was integrated and the total volume compared with the inflow volume. In nearly all cases, the volumes showed a close correlation, within approximately two percent. The mass flow of each nitrogen form was then calculated for each of the sampling times. The results of this calculation are plotted in Figure 13. The mass flow curves were then integrated for the time period between loadings to give the total mass of each form in the effluent. The total mass of each form was then divided by the volume of wastewater applied to determine the flow weighted effluent concentration. These are the values reported in appendix I.

PHYSICAL MEASUREMENTS

The effluent temperature was recorded with each sample. The average weekly bed effluent temperatures are shown in Figure 14.

Influent flow measurements for the flood loaded system were made with a totalizing propeller type, flow meter installed in the influent pipe. This meter was calibrated on site using a timed volume technique. The sprinkler system inflow was measured with precalibrated rate of flow controllers. The instantaneous flow rate and the time of pumping information was tabulated as part of the operational computer program. The printout gave the time of sprinkling and the total volume of wastewater loaded to each bed for each day of operation. Effluent flow measurements were made for individual beds several times during during each loading sequence using V-notch weirs. The weirs were fabricated from 0.47 cm (0.1875 in) thick aluminum plate and installed the channels of the effluent sampling manhole. Water heights behind the weirs were measured and flows were calculated. The weirs were precalibrated in the University laboratory. The calibration produced the following formula:

$$Q = 0.179\ (2g)^{0.5}\ (H)^{2.5}$$

where Q was the flow rate, g the gravity constant and H the distance from the bottom of the V-notch to the water surface.

The depth of water on the surface of the basin was measured to obtain the basin infiltration rate. This rate was calculated by subtracting the final water depth from the initial water depth and dividing the result by the elapsed time between the two measurements. The resulting average infiltration rate has been reported in cm/hr.

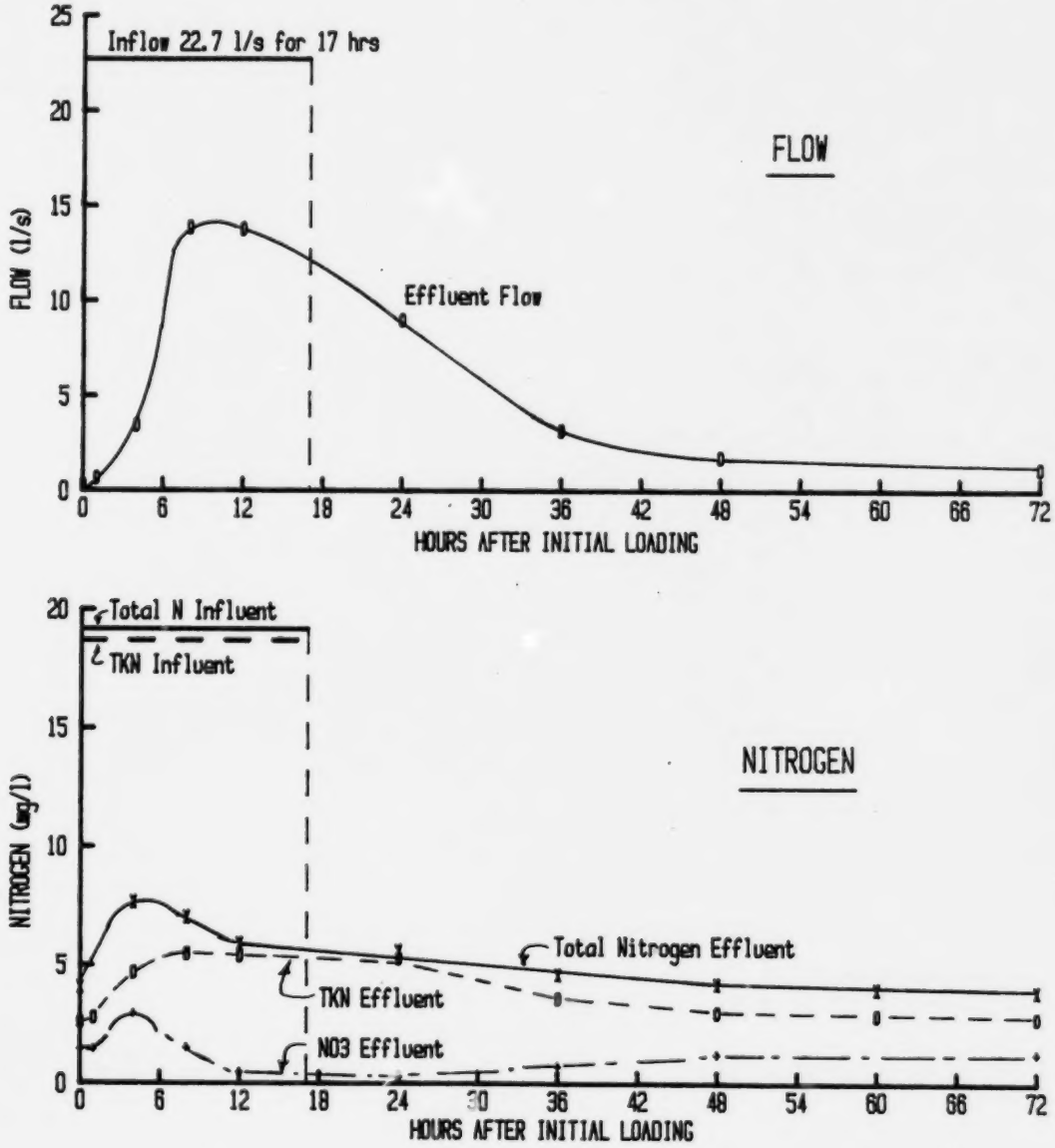

Figure 12. Influent and effluent flow and nitrogen pattern.

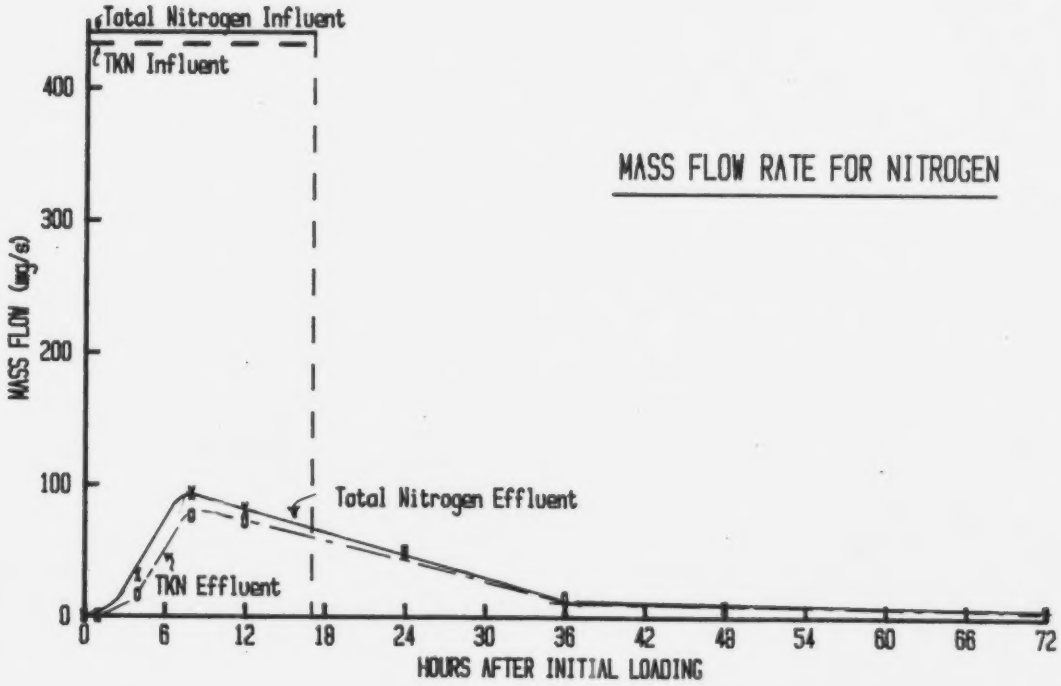

Figure 13. Mass flow patterns for the nitrogen forms.

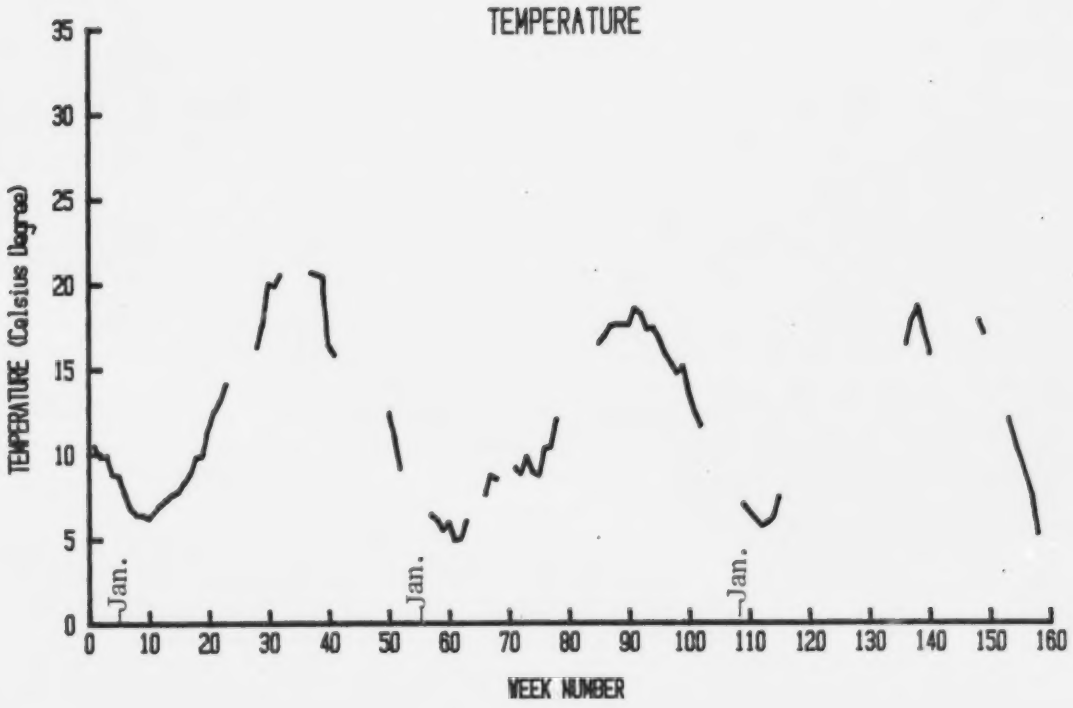

Figure 14. Effluent temperature pattern.

SECTION 5.

PERFORMANCE OF THE RAPID INFILTRATION SYSTEM

LOADING MODES

The average concentrations for the rapid infiltration bed influents and effluents as well as removal percentages for the total period of each loading mode are given in Table 6.

TABLE 6. AVERAGE CONSTITUENT CONCENTRATIONS AND REMOVALS

Constituent	Bed influent	Bed effluent	% rem.
Mode 1 (3 1/2 day)			
Nitrogen			
Ammonia-N	16.5 mg/l	6.5 mg/l	60
Nitrate-N	0.27 mg/l	1.85 mg/l	-
Organic-N	7.05 mg/l	0.85 mg/l	88
Total-N	23.82 mg/l	9.20 mg/l	61
T. Phosphorus-P	7.65 mg/l	1.33 mg/l	83
BOD-5	101 mg/l	8.8 mg/l	91
TOC	67.3 mg/l	10.2 mg/l	85
Suspended solids	51.2 mg/l	14.7 mg/l	71
Coliforms/100 ml			
Total	58.5×10^5	1.6×10^5	97
Fecal	13.4×10^5	0.65×10^5	95
pH	6.85	6.85	-
Calcium	41.6 mg/l	58.6 mg/l	-41
Magnesium	21.5 mg/l	21.5 mg/l	0
Sodium	56.6 mg/l	53.0 mg/l	6
Mode 2 (1 day)			
Nitrogen			
Ammonia-N	13.75 mg/l	3.23 mg/l	77
Nitrate-N	0.36 mg/l	4.58 mg/l	-
Organic-N	8.40 mg/l	1.06 mg/l	87
Total-N	22.51 mg/l	8.87 mg/l	61
T. Phosphorus-P	8.94 mg/l	0.53 mg/l	94
BOD-5	54.5 mg/l	3.8 mg/l	93
TOC	53.1 mg/l	6.7 mg/l	87
Suspended solids	53.9 mg/l	10.2 mg/l	81
Coliforms/100 ml			
Total	-	-	-
Fecal	14.3×10^5	0.93×10^5	94

(continued)

Table 6. (continued)

Constituent	bed influent	bed effluent	% rem.
Mode 3 (sprinkler)			
Nitrogen			
Ammonia-N	17.85 mg/l	1.28 mg/l	93
Nitrate-N	0.13 mg/l	10.50 mg/l	-
Organic-N	6.76 mg/l	0.64 mg/l	91
Total-N	24.74 mg/l	12.42 mg/l	50
T. Phosphorus-P	7.13 mg/l	0.55 mg/l	92
BOD-5	80.4 mg/l	2.2 mg/l	97
TOC	54.8 mg/l	5.0 mg/l	91
Suspended solids	53.5 mg/l	6.0 mg/l	89
Coliforms/100 ml			
Total	-	-	-
Fecal	-	-	-

Some of the measured chemical constituents of the wastewater including pH, sodium and magnesium were essentially unchanged during the rapid infiltration process. The slight increase in calcium probably resulted from dissolving of calcium carbonate deposits in the bed material.

Coliform removals were significant, but relatively high concentrations remained in the process effluents when flood application was used. Coliform densities were not monitored with the sprinkler loading mode. Inspection of the underdrain system revealed that biological growth was occurring and the high effluent coliform counts may have been due to regrowth of these organisms in the underdrains. A similar result of coliform regrowth was reported for a long term operation at the Hollister, California rapid infiltration site (7). The results of this study show that the long term use of underdrained rapid infiltration beds may require disinfection of the effluent prior to discharge into a surface receiving water.

The values shown include periods of study when the variables tested were not at optimum. In order to judge a more optimized system performance, Table 7 has been constructed with a summary of the removal percentages for the important parameters shown above and with the efficiencies resulting under the best condition studied based on four continuous weeks of operation.

TABLE 7. COMPARISON OF THREE LOADING MODES
AVERAGE AND BEST 4-WEEK RESULTS

	flood (3 1/2 d) % rem.		flood (1 d) % rem.		sprinkler % rem.	
	ave.	4-week	ave.	4-week	ave.	4-week
Total Nitrogen	61	76	61	77	50	65
Total Phosphorus	83	87	94	97	92	98
BOD-5	91	91	93	96	97	99.5
TOC	85	85	87	91	91	96
Suspended solids	71	73	81	89	89	98

The first ten weeks of the study were not included in the selection of the best four weeks of operation because the beds had been rested for more than a year and this period of loading did not represent normal operation. Similarly, the first sprinkler cycle was probably not representative due to a long resting cycle for system modification.

For each of the wastewater pollutional parameters of nitrogen, phosphorus, BOD, TOC and suspended solids, the influent and effluent concentrations and removal percentages are shown. The major operational variables were analysed for their effect on the performance of the system. They included loading rate, infiltration rate, wastewater strength and temperature and number of loadings after a resting period. The operational variables having the greatest influence on the percent removal of each of the pollutants are discussed.

NITROGEN REMOVAL

The use of rapid infiltration beds to remove nitrogen from wastewater involves the creation of aerobic conditions for nitrification and reducing conditions for denitrification simultaneously or sequentially in such a manner as to prevent pulses of ammonia or nitrate from being released in the effluent during any portion of the loading and infiltration cycle.(8,9,10) Removal of nitrogen by ammonia volatilization has been reported to be only a minor factor with high rate systems.(11,12)

Denitrification requires a carbon source for the denitrification chemical reaction to proceed. Lance and co-workers (10), as well as others, have demonstrated that increased carbon to nitrogen ratios enhanced the denitrification reaction. They (13) have also shown that high soil moisture content, near or at saturation, produced the anoxic condition required for maximum denitrification. Lance, et al. (13), attained optimum conditions for nitrogen removal by reducing infiltration rates.

In an earlier study at the same site and using the same system as this research, (14), it was found that nearly complete (>95%) ammonia conversion to nitrate was accomplished when applying either primary or secondary effluent with typical loading rates in the range of 15 to 45 meters per year (50 to 100 ft/yr). In that study, high infiltration rates were maintained with frequent resting and scarification. Nitrogen removal resulting from denitrification was relatively low, in the range of fifteen percent.

The present study was oriented towards producing conditions for nitrogen removal. Primary effluent was used to provide a carbon source for the denitrifying organisms. The average BOD/N ration was 4.75 and the average TOC/N was 2.82.

The beds had been standing idle for a year and they were scarified prior to any wastewater application. For the first ten weeks of loading, the influent percolated through the beds very rapidly. Infiltration rates were high (>50 cm/d) and the bed effluents were highly nitrified but with less

than forty percent nitrogen removal. These results are shown as the beginning of the time-history curves of figures 15, 16, and 17, for each of the rapid infiltration beds. The top curve on each graph shows the loading rate as a function of the week of loading; the next curve the infiltration rate; the third curve the total nitrogen concentration of the influent and effluent (solid dark lines) and the ammonia nitrogen concentration of the influent and effluent (lighter solid lines) and the nitrate nitrogen concentration of the effluent (dashed lines). Nitrites were included in the nitrate measurements. Organic nitrogen and influent nitrate nitrogen are not shown on the curves except that they are included in the total nitrogen values. All individual values are given in the Appendix. The bottom curves show the percent removal of total nitrogen.

Soon after the tenth week of loading, the infiltration rate dropped rapidly with each loading. This was caused by a build up of a solids mat on the surface of the beds. The mat consisted of solids strained from the wastewater during the infiltration periods. The reduced infiltration rate caused the beds to be flooded over for a large portion of the 3.5 day between loadings. When the infiltration rate dropped below 20 cm/day (5 gpm/ft^2), the beds were flooded over continuously between loadings. As soon as the beds became flooded over on a continuous basis, the nitrate level in the effluent dropped and the ammonia concentration began to increase. The beds were rested and scarified after 23 weeks of loading. At that time the nitrogen removals were still high, averaging more than seventy percent, but the water was on the verge of flowing over the top of the side berms of the beds near the end of each loading period.

At the beginning of the study, a nitrate flush occurred with the first loading after each resting and scarification sequence. With further loadings, the infiltration rate decreased and the beds became flooded over again and the nitrogen removal rate returned to the seventy percent range. After the third loading sequence it was found that by reducing the length of the resting period and using very light or no scarification that the nitrate flush could be nearly eliminated. The loading pattern was continued using shorter periods between restings until the sixty-eighth week of the study. It was obvious from the data, that the ammonia level in the effluent was continually rising and the total nitrogen removal percentage was declining. Beds 2 and 3 were removed from the loading sequence so that the sprinkler system could be installed and bed 1 was loaded daily at a rate in the range of 5 cm (2 in.) per day. It can be seen from the curves that the ammonia level in the effluent decreased from week 71 to week 102 and the removal percentage increased. Beginning with week 109, the sprinkler system was operational on beds 2 and 3. To prevent an overpressure in the influent pipe from the pump at the primary clarifier to the plots, excess wastewater was allowed to overflow into bed 1 whenever the other two beds were sprinkling. The overflow produced an unregulated flow on bed 1 and it was not monitored after week 115.

The sprinkler systems on beds 2 and 3 were manually operated from week 109 until week 117. The low loading produced the typical steep decline in the effluent nitrate curve. Construction within the treatment plant caused the system to be down from week 118 until week 135. After resuming

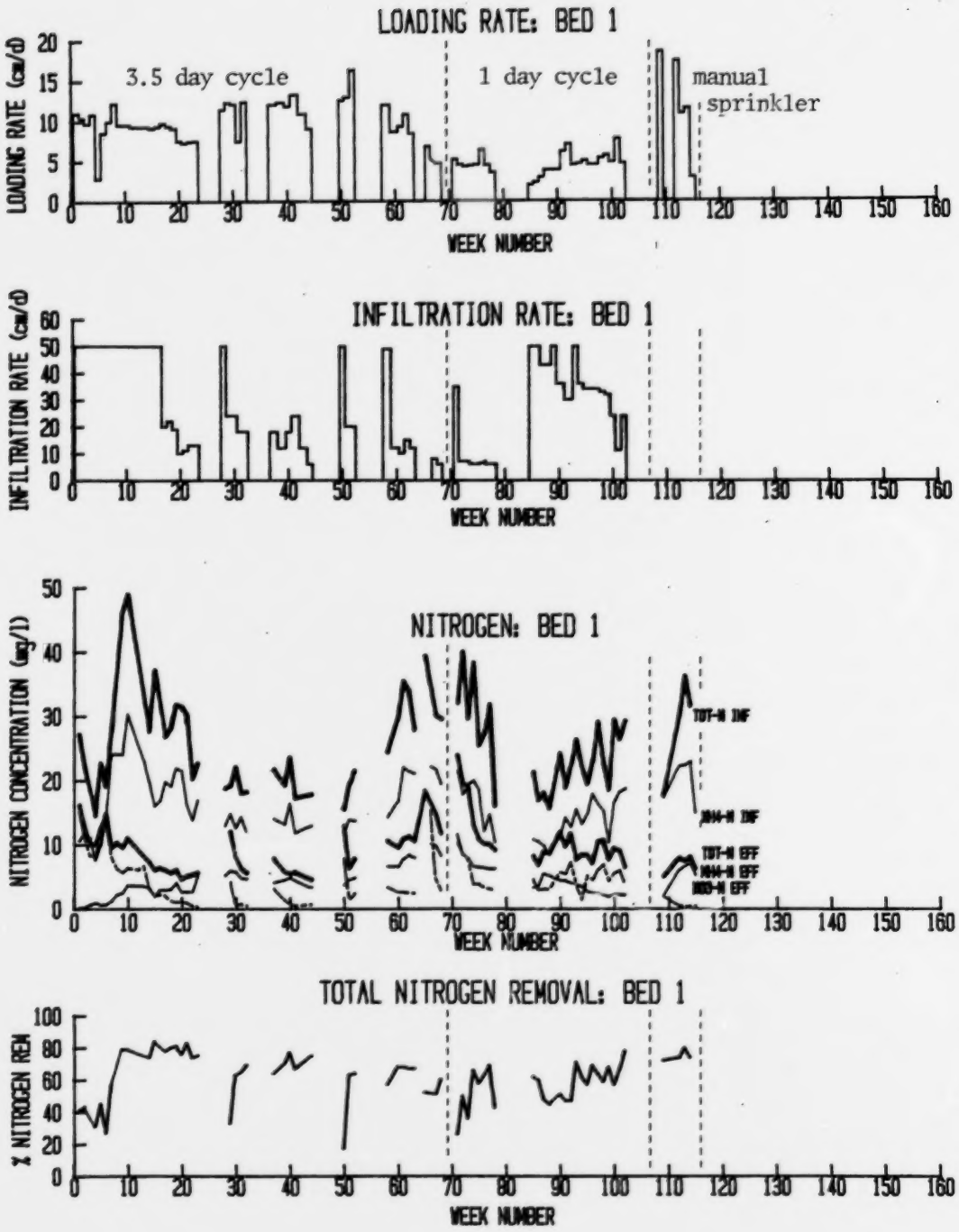

Figure 15. Nitrogen analysis for bed 1.

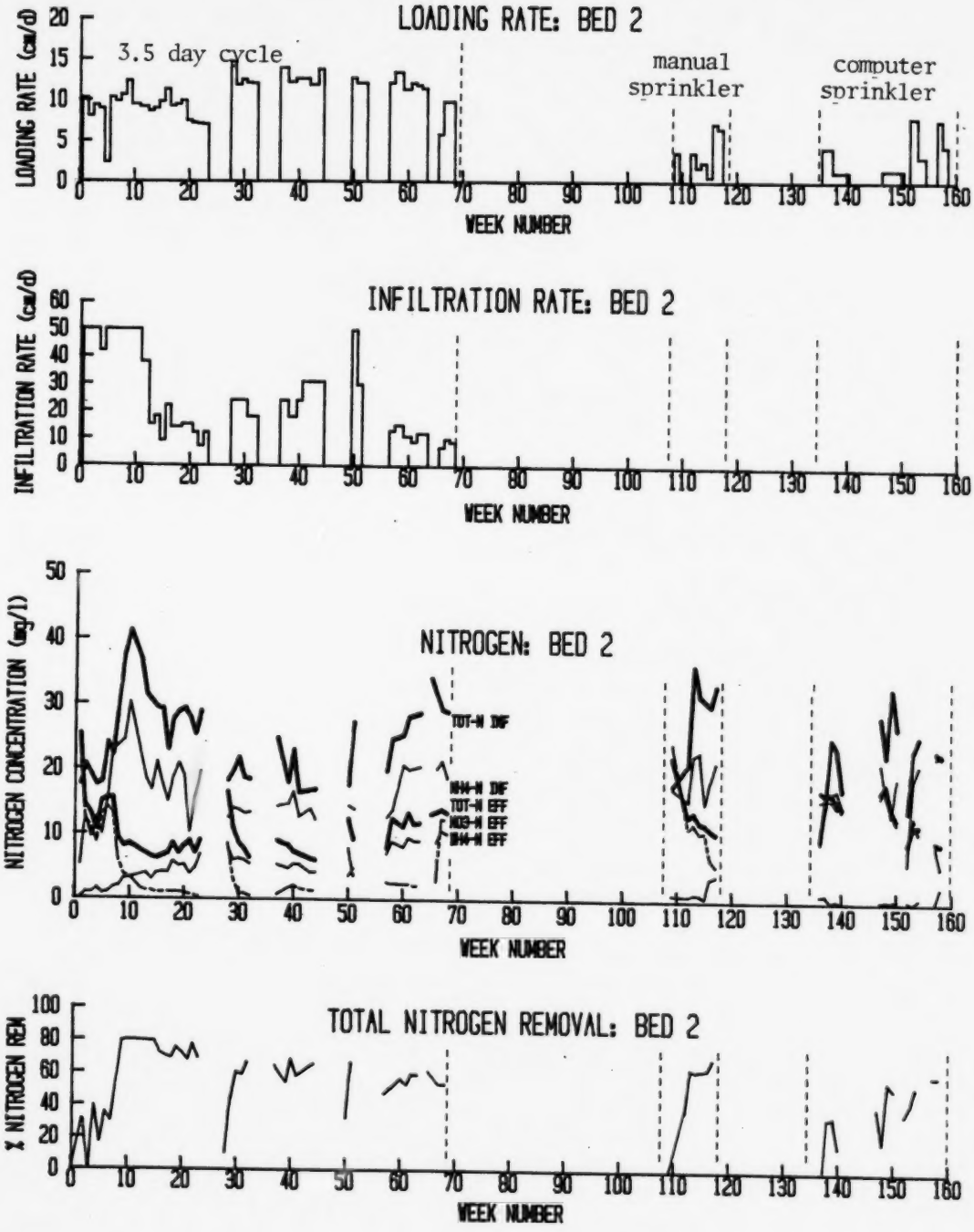

Figure 16. Nitrogen analysis for bed 2.

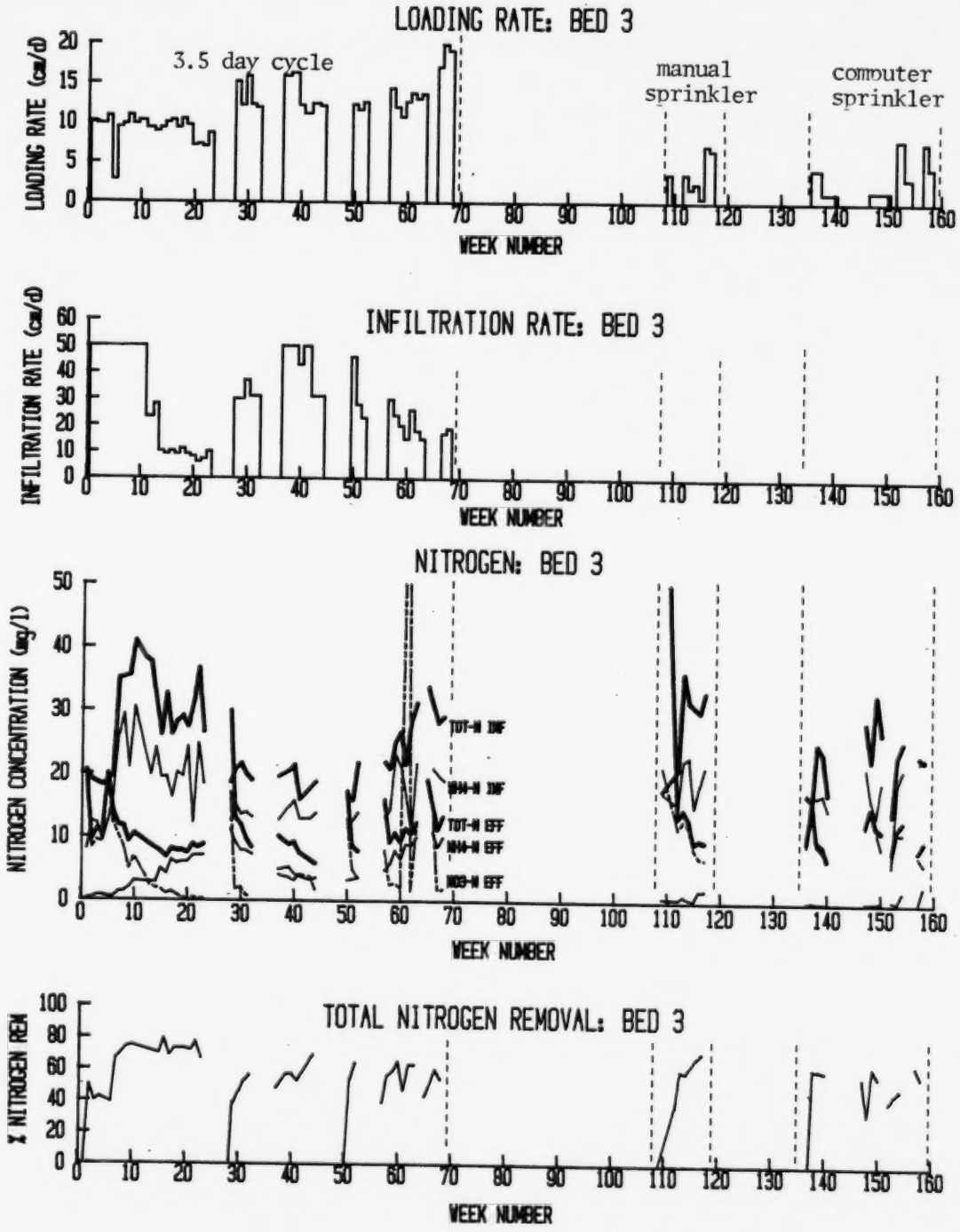

Figure 17. Nitrogen analysis for bed 3.

operation, the loading was computer controlled. Several different soil moisture control points were tried, with each sequence producing higher nitrogen removals, but optimum steady state operation could not be obtained prior to the end of the field testing at week 158.

Analysis

The initial loading rate, during the first twenty weeks of the study, of 0.72 meters/week (2.36 ft./wk.) producing a total nitrogen loading of 171 Kg/Ha-wk (150 lb/ac-wk) caused an overloading of the system resulting in continued lowering of the percent nitrogen removal from approximately 80 percent to near 60 percent. It was shown in an earlier study (14), that this loading rate was acceptable when ammonia removal through nitrification was the objective. This average loading rate is approximately 15 percent of the saturated hydraulic conductivity. This is greater than the maximum recommended hydraulic loading of 10 percent of the saturated hydraulic conductivity (15). When the loading was reduced to 0.33 meters/week (1.07 ft./wk) with a total nitrogen loading of 77.7 Kg/Ha-wk (70 lb/ac-wk) beginning with week 71, the nitrogen removal increased from near 60 percent to approximately 80 percent. Loading each day instead of twice per week may have contributed to the improvement by providing a more constant head of water on the beds and a more uniform interstitial velocity and increased contact time. Reduced effluent ammonia concentration with reduced loading rates has also been observed at by Bouwer and coworkers (16) at Flushing Meadows.

It was found in this field study that the behavior of the system was somewhat different than that reported for laboratory column studies. The literature shows for column studies (13, 17, 18) that a delicate balance between oxidizing and denitrifying conditions is needed and that this can best be achieved by alternating flooding and drying cycles and that long periods of completely flooded over conditions caused a loss of nitrification ability in the soil. In this field study the periods between drying cycles were greatly extended. The system was operated in a continuously flooded over condition for periods of two months without a major change in the extent of nitrogen removal, (weeks 15-23, 71-78, 88-102). The flooded over condition resulted from low infiltration rates caused by the formation of the solids mat on the surface of the beds. The only times when poor nitrogen removals (<50 percent) were observed was immediately after resting and scarification. The graph of the experimental data in Figure 18 shows that removals were nearly constant when the infiltration rate was below 20 cm/d (8 in./d.) and this rate allowed for the continuous flooding over of the beds when they were loaded every three and one-half days. A somewhat similar result has been reported by Lance and Co-workers (13) and their curve is shown, without including the data points, as the dashed line in the data analysis.

The scarification broke up the solids mat. This allowed high infiltration rates for several loadings after resting until the solids mat was reestablished. During the high infiltration rate periods, the effluents contained high nitrate concentrations. Once the flooded over condition was established, high nitrogen removals resulted.

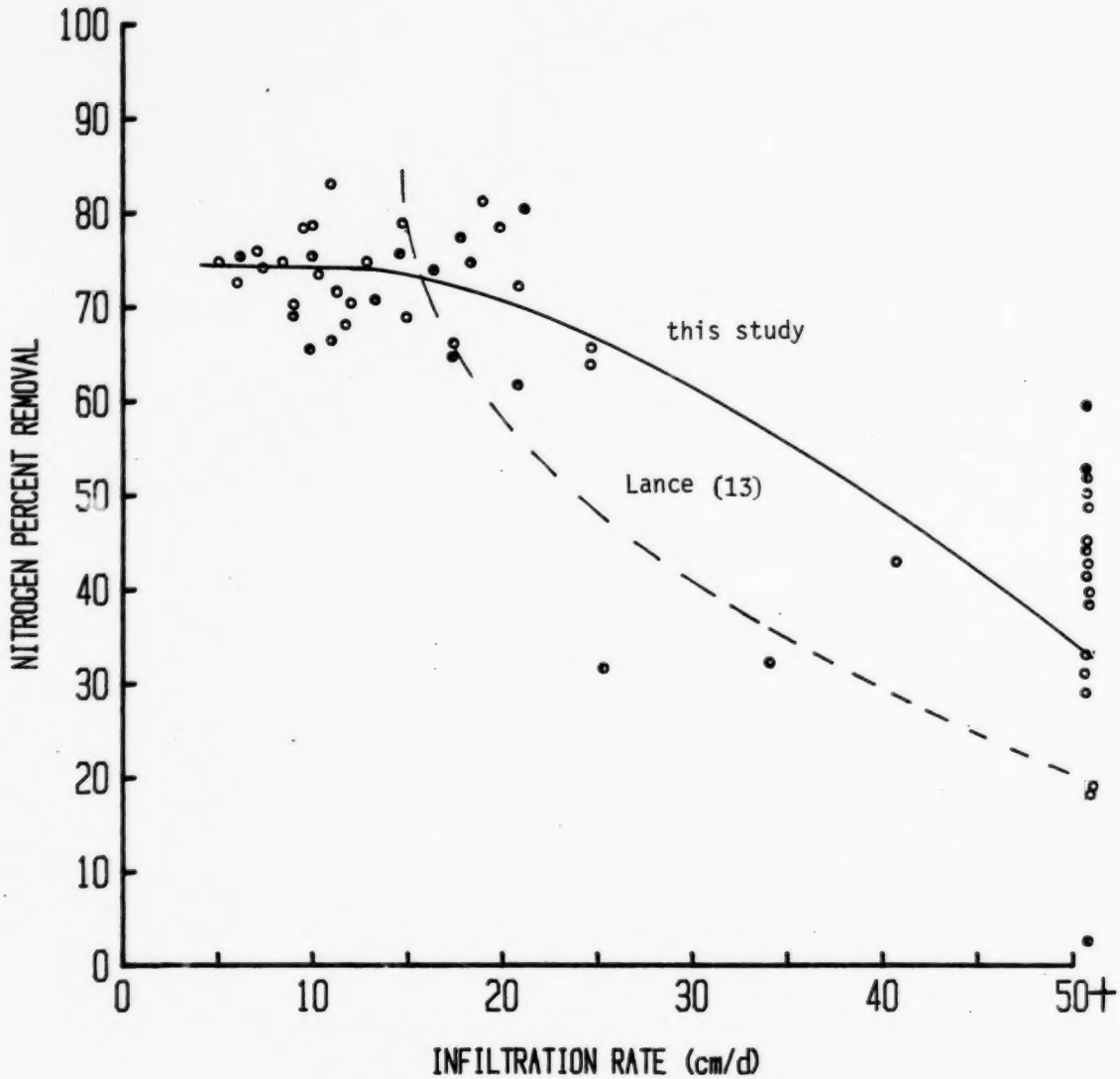

Figure 18. Nitrogen removal as a function of infiltration rate.

In this study, the oxygen necessary for the biological nitrification in the nitrification-denitrification sequence was apparently available from sources other than that of the drying cycle. With the continuous flooding of the system, diffusion of oxygen through the surface of the pond will be minimal. Therefore the oxygen may have diffused through the unsaturated soil surrounding the infiltration basin and through the unsaturated soil directly beneath the basin. The underdrain pipes may have also aided in bringing oxygen to the soils within the basin. It should be noted that the entire bed profile would not be saturated with water even though the surface was flooded, since the wastewater solids were concentrated at the soil surface and thereby restricted water flow through the soil surface. If this hypothesis is true, the maximum loading for nitrification will also depend on the size and geometry of the infiltration beds when one is trying to establish denitrifying conditions by monitoring a saturated soil surface.

It appears that one major factor affecting the effluent nitrogen concentration was the nitrogen mass loading rate with respect to the cation exchange capacity of the soil in the uppermost few centimeters of the beds. The cation exchange capacity is usually greater for soils of higher organic content (19). Soil organic matter, along with that in the wastewater and from the surface mat after it has been disked into the bed during scarification, provides the energy source for the denitrifying bacteria.

The thickness of the surface soil horizon did not seem to be a major factor in nitrogen removal in this research. Beds 2 and 3, each with a soil horizon of about 15 cm (6 in.) gave very similar removals to bed 1 where the soil layer was 75 cm (30 in.) thick.

Other researchers working with land treatment systems have reported results with very high nitrogen removals. In one study, by using soil columns, it was found that increased nitrogen removals were achieved by ammending the upper layer of the soil with wastewater sludge to increase the organic matter content (20). In another study, the rapid infiltration beds at Hollister, California were analysed. The soils had relatively high organic matter content and low infiltration rates. The high suspended solids concentrations of the influent also helped reduce infiltration rates by producing a rapid buildup of the surface solids mat. The nitrogen mass loading was relatively low (16.7 Kg/Ha-d) and the reported nitrogen removal was 93 percent (21). A recent study completed at the University of Colorado, Mountain Research Station (22), utilized low rate forest land treatment. Extremely low nitrogen loadings (7.0 Kg/Ha-wk), hydraulic loadings (0.05 meters/week, 0.16 ft./wk.) and BOD/N ratio (0.55) were utilized. The site was located in a position where the sandy clay loam soil surface was near saturation at all times. Renovated water samples were obtained by evacuated lysimeter cups and the average removal of nitrogen (ammonia plus nitrate) was ninety-five percent.

Temperature effects were analysed but it was concluded that the removal of nitrogen was not significantly different between summer and winter wastewater temperature conditions. Similar findings have been reported by other researchers (23). Equations have been developed in the literature

(24), that indicate that the hydraulic loading rates should be reduced for winter operation. During the first year of this study, loading rates of 11 cm/day were used with wastewater temperature of 5°C and nitrogen removals were similar to those encountered throughout the year.

Most of the rapid infiltration process sites in the U.S. have reported results (25) for nitrogen removal in the range of 30 to 70 percent. Future installations can be designed to obtain greater removals if a site is selected with a 15-30 cm (6-12 in) surface soil horizon with a high organic carbon and high cation exchange capacity and with a low but adequate infiltration rate overlying a highly permeable parent soil. A low nitrogen mass loading rate and application techniques that maximize soil moisture content while maintaining sufficient oxygen for nitrification should be used. There is a delicate balance between maintaining just sufficient oxygen to nitrify the applied wastewater and having too much oxygen to maintain denitrification. Aeration should be utilized only when there is unacceptable ammonia leakage into the effluent or if necessary to rest the beds to maintain the required hydraulic loading. Scarification should be minimized and used only when resting alone will not restore the necessary infiltration rate. The individual beds should be sized small enough to provide for uniform loading of the influent stream.

PHOSPHORUS REMOVAL

Phosphorus removal from wastewater was evaluated in conjunction with the operating conditions needed for nitrogen removal. Land treatment of phosphorus involves the two sequential reactions of adsorption of the phosphate ion and precipitation of solid phosphorus containing minerals that are retained in the soil matrix.(25,26) The precipitation (mineralization) usually appears to be the rate limiting step. When a system is overloaded with respect to phosphorus, the rate of mineralization becomes inadequate to continually renew the sites for the adsorption reaction, and the phosphorus concentration in the process effluent increases.

The phosphorus removals in this study are summarized in Figures 19, 20 and 21. It can be seen from the lower curves in each of the figures that the treatment system during the initial 44 weeks of the research was unable to maintain 90 percent removal efficiency. Long resting periods in the following weeks caused the system to completely recover by week 50. Lower loading rates and more frequent resting periods maintained efficient phosphorus removals for the remainder of the study. Similar findings have been reported by other investigators (27,28). Further analyses of these data are shown in Figure 22. The upper curve relates the 3-bed average percentage phosphorus removal with the week of loading. The center curve shows the mass removal rate per unit area of bed for individual weeks during the study. The bottom curve shows the cumulative, long term average mass removal rate, including resting periods as a function weeks of loading. Dashed lines have been drawn at a mass removal rate of 0.3 g/m^2-d (3.0 Kg/Ha-d) and this appeared to be the rate of the mineralization for the concentration of phosphorus in the applied wastewater and the system topsoil characteristics. The high initial removals during the first ten weeks of the study probably

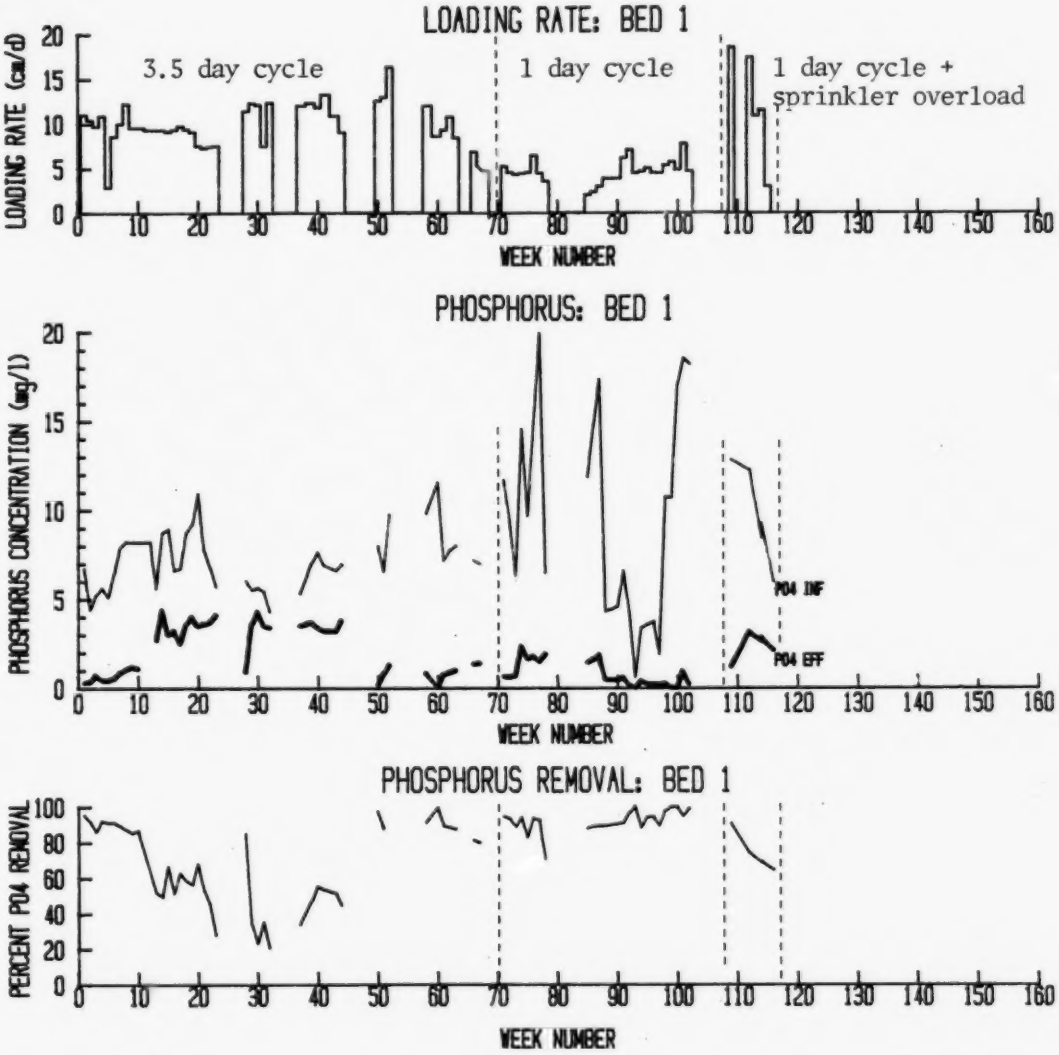

Figure 19. Phosphorus analysis for bed 1.

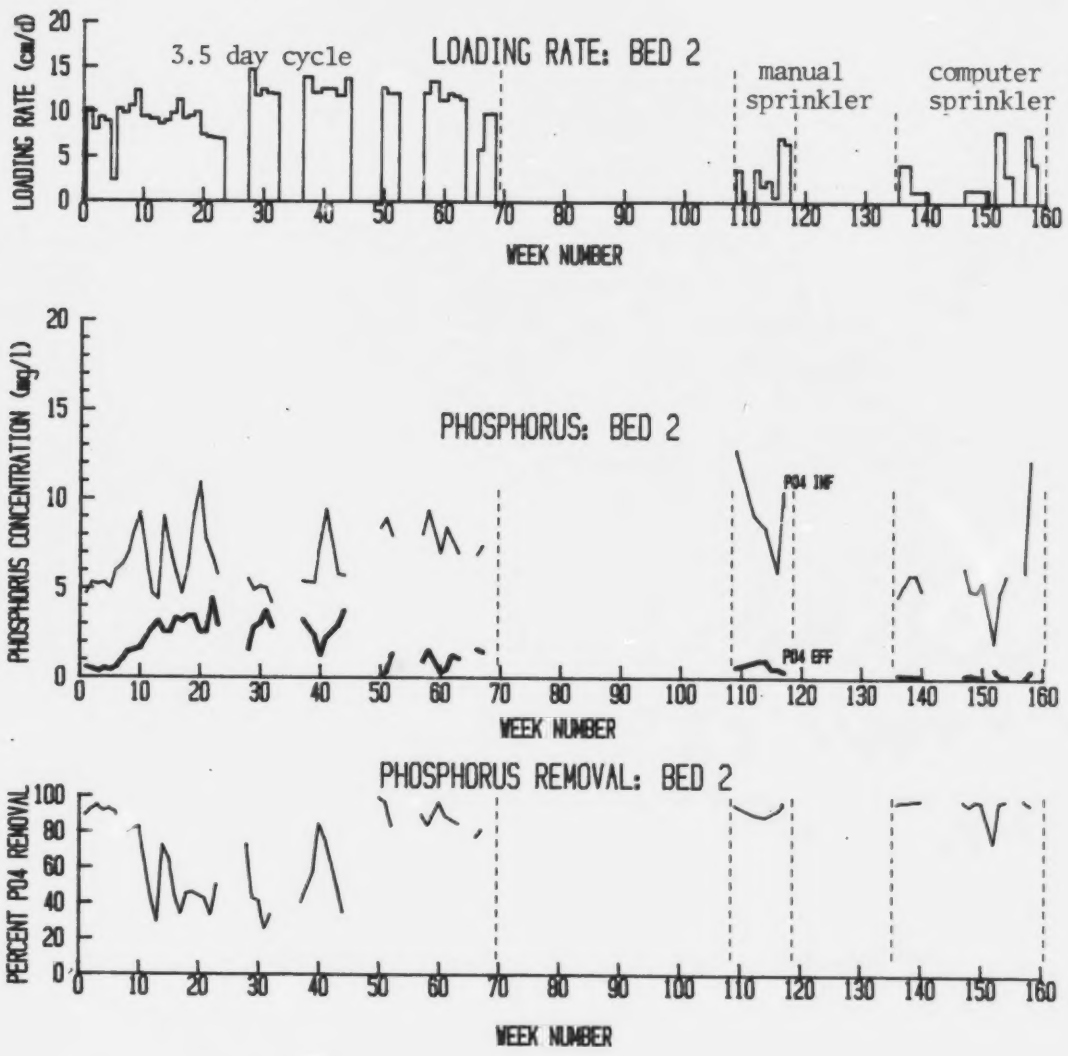

Figure 20. Phosphorus analysis for bed 2.

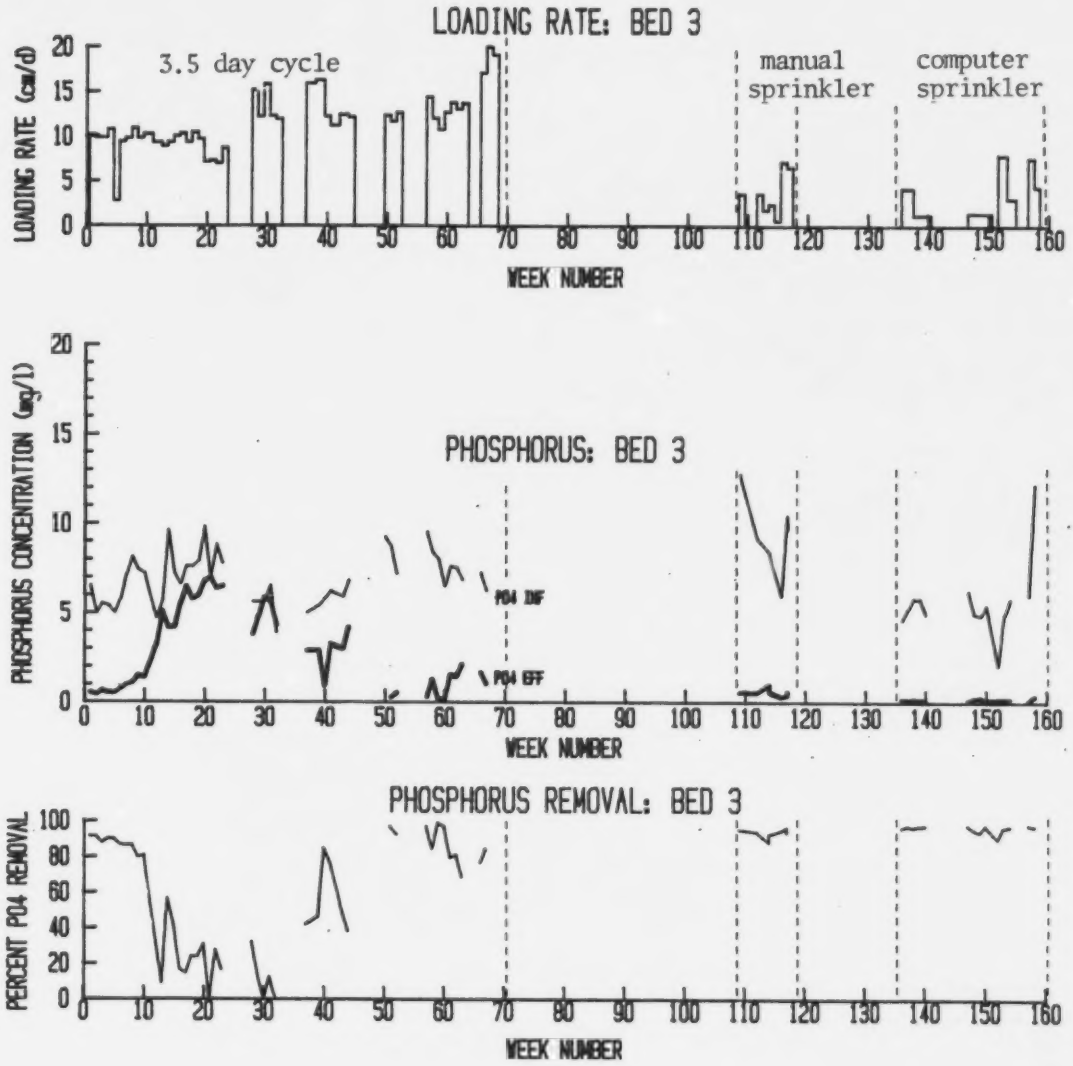

Figure 21. Phosphorus analysis for bed 3.

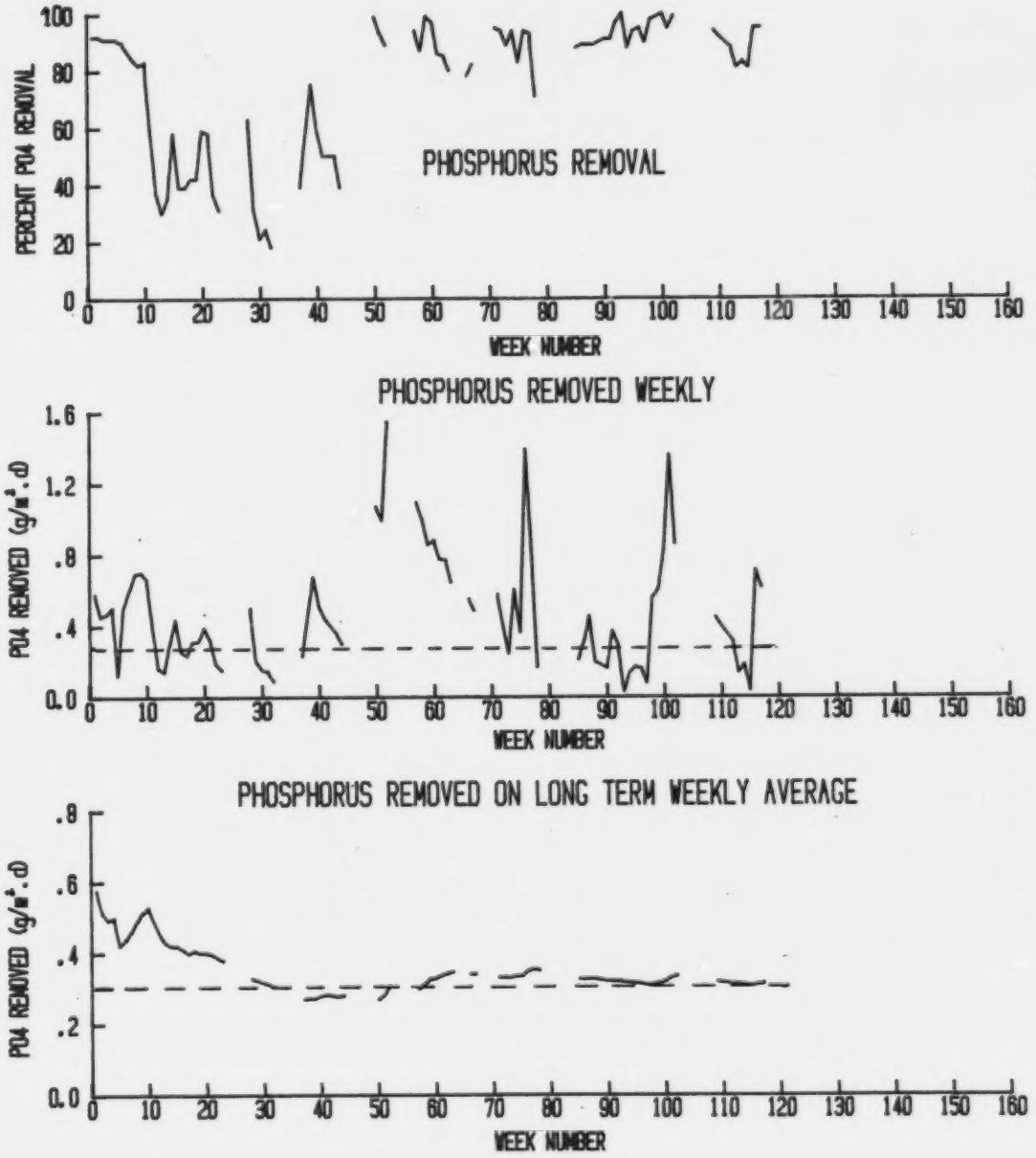

Figure 22. Effect of mass loading rate on phosphorus removal.

resulted from the fact that the system had not recieved any wastewater loading for more than a year prior to the initial loading of this research project.

The long term loading effects can be evaluated from the upper and lower curves. When the cumulative loadings were above 0.3 g/m^2-d, the removals went down because the mineralization could not free the adsorption sites rapidly enough to maintain the required adsorption capacity. After week 44, the cumulative loading rate was lowered and the system recovered rapidly. The cumulative loading rates were held at approximately the target level for the remainder of the study and the removals remained in the ninety percent plus range.

The short term effects can be related to the center curve. Observing the data for weeks 57 to 63, although the long term cumulative loadings including resting periods were near 0.3 g/m^2-d, the short term weekly loadings were about three times this level. The removals at the beginning of the loading series were in the high ninety percent range and they declined rapidly over the six week period. The same tendency can be observed for weeks 71 through 78. For weeks 85 through 98, the opposite tendency can be seen to result from weekly loadings of less than the mineralization rate of 0.3 g/m^2-d. There is a direct relationship between the removal tendency on the short term and the weekly loading rate, although there is a week or two lag in the removal tendency when the loading is changed abruptly, as evidenced in weeks 77, 100 and 115.

Three periods were selected from the data array (weeks 15-19, 74-78 and 92-96) as steady state condition for the points (squares) in Figure 23. A line was constructed through the points to illustrate the removal capacity of the soil in this research. The reported results of other researchers have also been shown.(29-35) The curve illustrates that there was a very discernible maximum loading rate that will give high removals and there was very little tolerance for overloading. The other researchers points show that the mineralization rate may have been quite different for the various soils encountered in the different research projects and that it may become a lower value after long term operation of a site. The mineralization rate is dependent on the depth and type of soil, the resting period and the water and soil chemistry, including the pH, calcium and phosphate contents.

The effect on phosphorus removal from continuous weeks of loading following a resting period is shown in Figure 24. The data for weeks 28 through 44 were not included in this plot because the system had not fully recovered from the initial overloading of the first 23 weeks. The curve illustrates the general slight decline in performance for the first six weeks of loading after resting and the steep decline that was observed in the long, initial 23 week loading sequence. The shape of this curve is completely dependent on the mass loadings used in this study.

Liquid loading rates influenced removals as shown in Figure 25. The rather poor correlation probably resulted from the fact that this curve does not account for waste strength and the mass loadings have been found to give a better account for system performance.

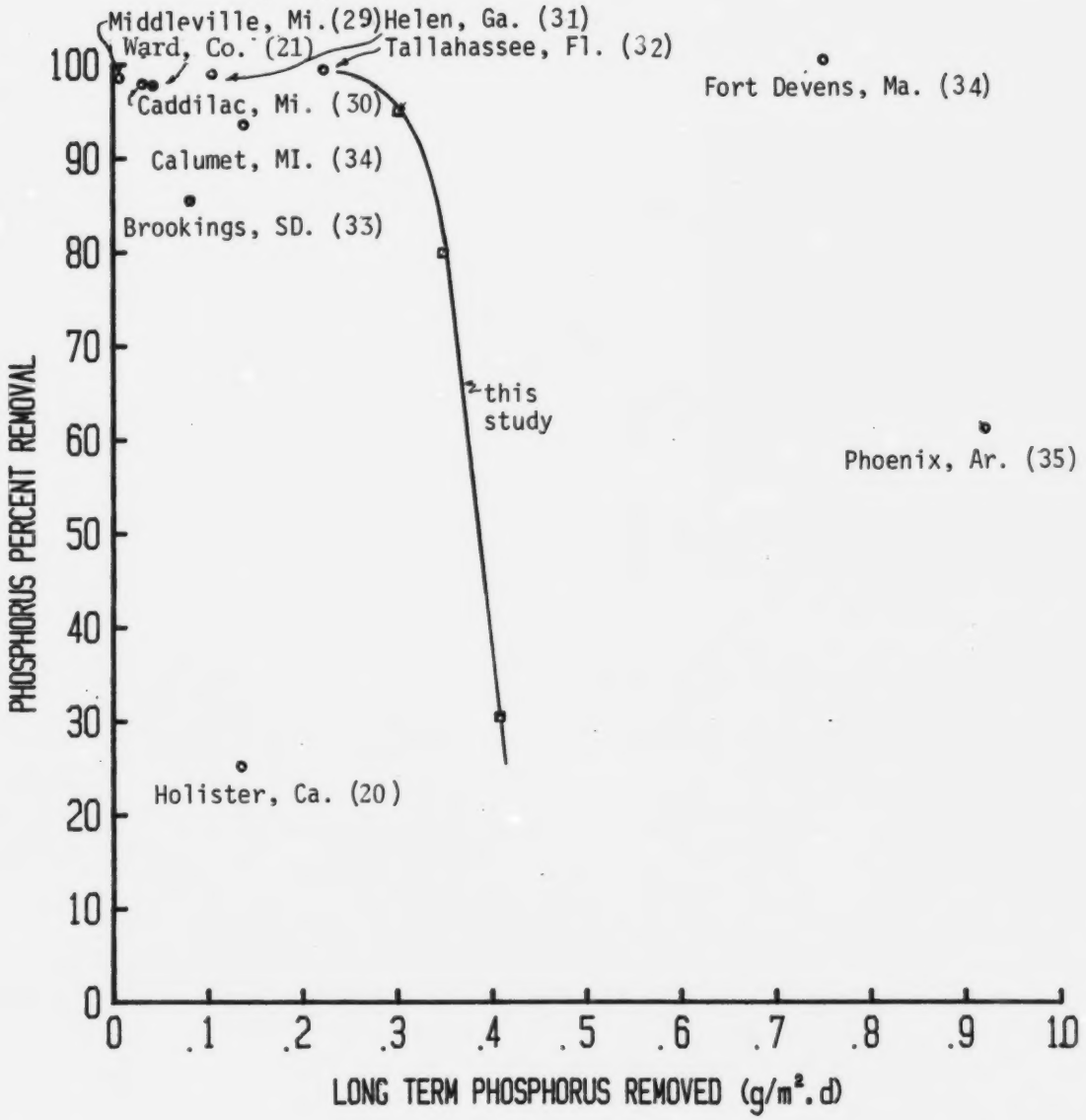

Figure 23. Phosphorus removal comparison with other studies.

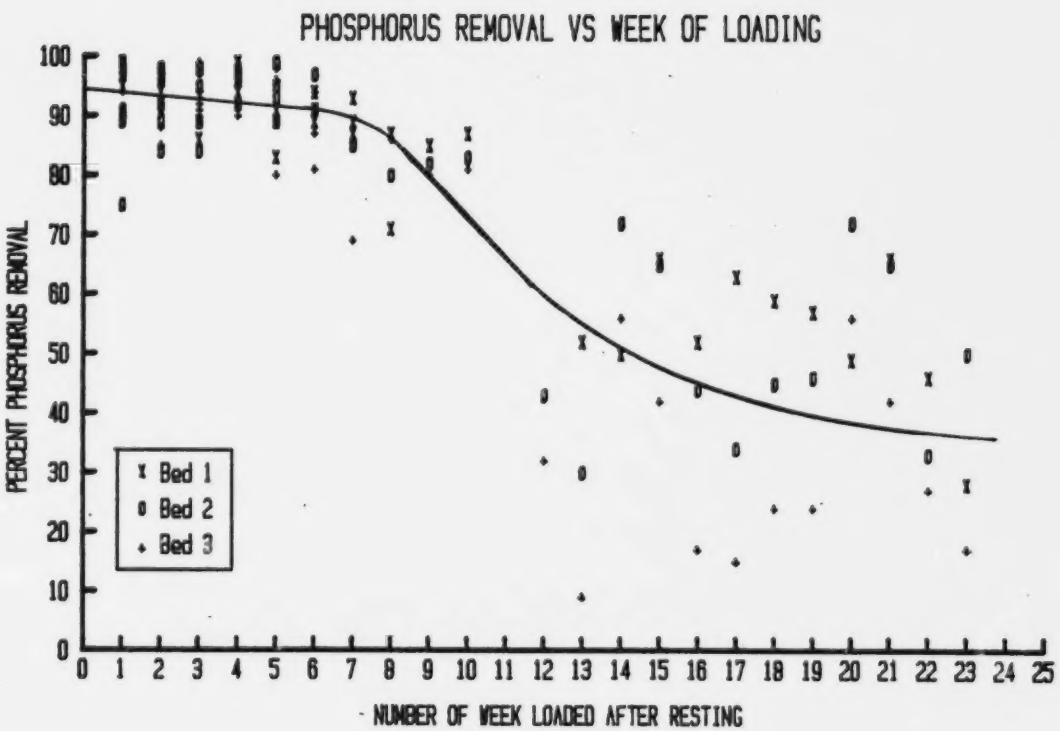

Figure 24. Phosphorus removal relationship with weeks of loading.

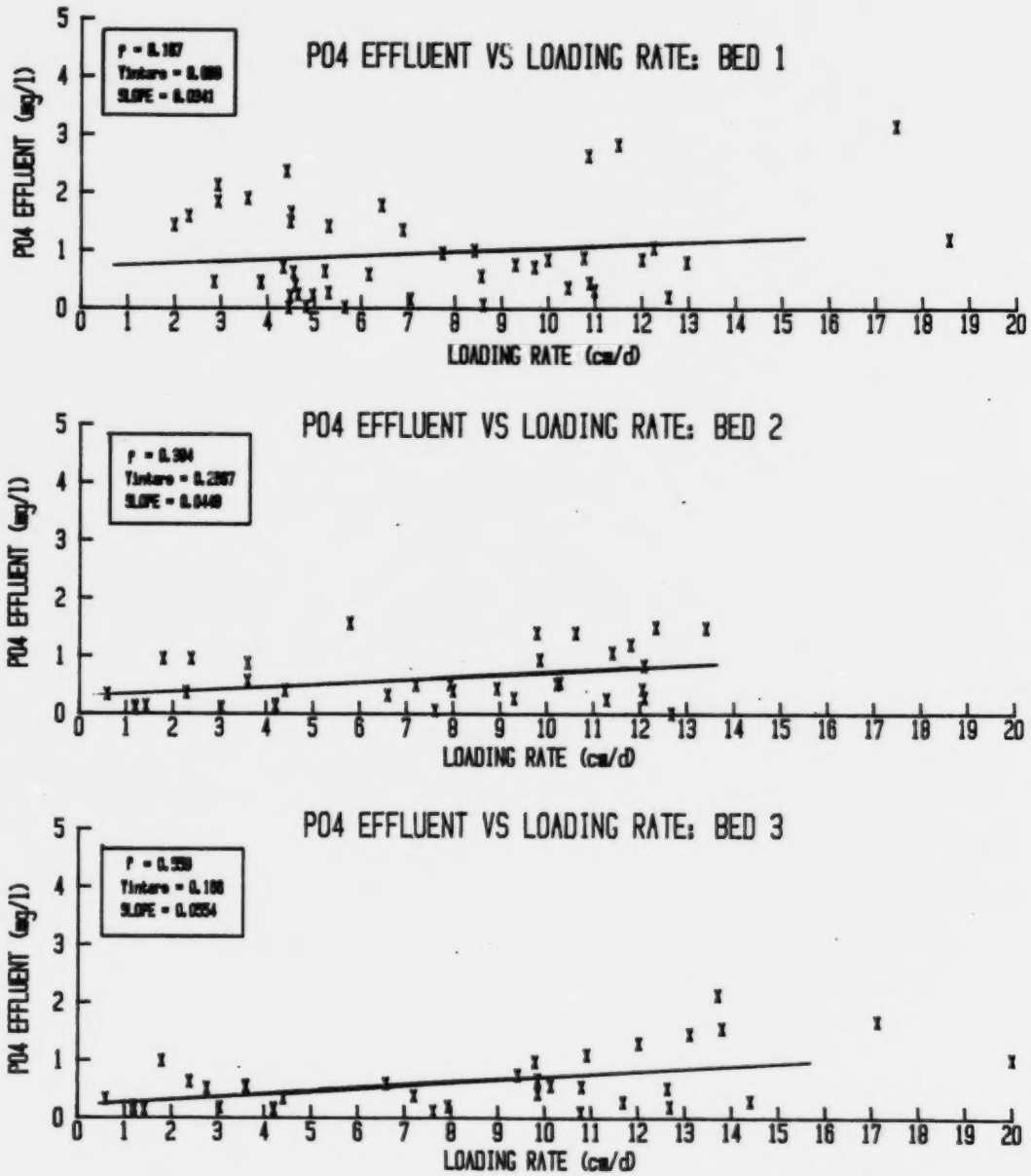
PO4 EFFLUENT VS LOADING RATE: BED 1
PO4 EFFLUENT (mg/l)
LOADING RATE (cm/d)
PO4 EFFLUENT VS LOADING RATE: BED 2
PO4 EFFLUENT (mg/l)
LOADING RATE (cm/d)
PO4 EFFLUENT VS LOADING RATE: BED 3
PO4 EFFLUENT (mg/l)
LOADING RATE (cm/d)

Figure 25. Effect of hydraulic loading on phosphorus removal.

The soil horizon of bed 1 was 75 cm (30 in.) thick while that of beds 2 and 3 were only about 15 cm (6 in.) thick and all three beds showed similar performance. Bed 3 had slightly lower removals when overloaded but in view of the curve of Figure 20, it appeared to have a mineralization rate about fifteen percent less than that of the other two beds. Other researchers (36-41) have also observed that the upper portion of the soil layer provides the largest contribution to the phosphorus removal.

Analysis

It appears from the data presented that phosphorus removal depends to a large extent on the cumulative long term and short term mass loading rates and on the mineralization rate characteristic of the soil. Phosphate precipitation involves complex chemical equilibrium reactions related to the water and soil pH, Eh, calcium, iron, aluminum or fluoride composition. For the near neutral wastewater and soil pH's of this study, the soil calcium content probably had the greatest influence on the mineralization rate.(24,42,43)

The field observations of this study are consistant with theories presented (44) which attempt to describe prosphorus reactions as a first order kinetic reaction plus rapid sorption. The high initial removal in Figure 22 is likely due to the long resting time prior to the initiation of this study. The shape of the data presented in Figure 23 is consistent with first order kinetic theory. This would suggest it would be necessary, for this soil, to increase the travel distance prior to collection of the renovated wastewater if one wanted high phosphate removal along with high loading rates.

BOD AND TOC REMOVALS

BOD and TOC gave similar patterns of removal for the rapid infiltration process. Since BOD is a more standard wastewater treatment pollution parameter, the curves for this constituent are shown in Figures 26, 27 and 28 and will be discussed. The rapid infiltration process produced high removals of BOD under all operating conditions. The most significant parameter affecting BOD removal appeared to be the hydraulic loading rate and this correlation is shown in Figure 29 for each of the beds. The least-squares analysis gave some correlation although it was not strong and this was due to some extent to the natural variance that results from the measurement of low BOD levels. The least-squares analysis produced one positive, one negative and one near-zero intercept and somewhat similar slopes.

Analysis

Slow filtration through granular earth materials is a very effective and reliable method for removing BOD. Increased filtration rates reduced the capture of smaller organic particles and shortened the contact time for biological adsorption and decomposition and thereby decreased the BOD removal slightly. Effluent BOD's were all below 20 mg/l and when the loading rate

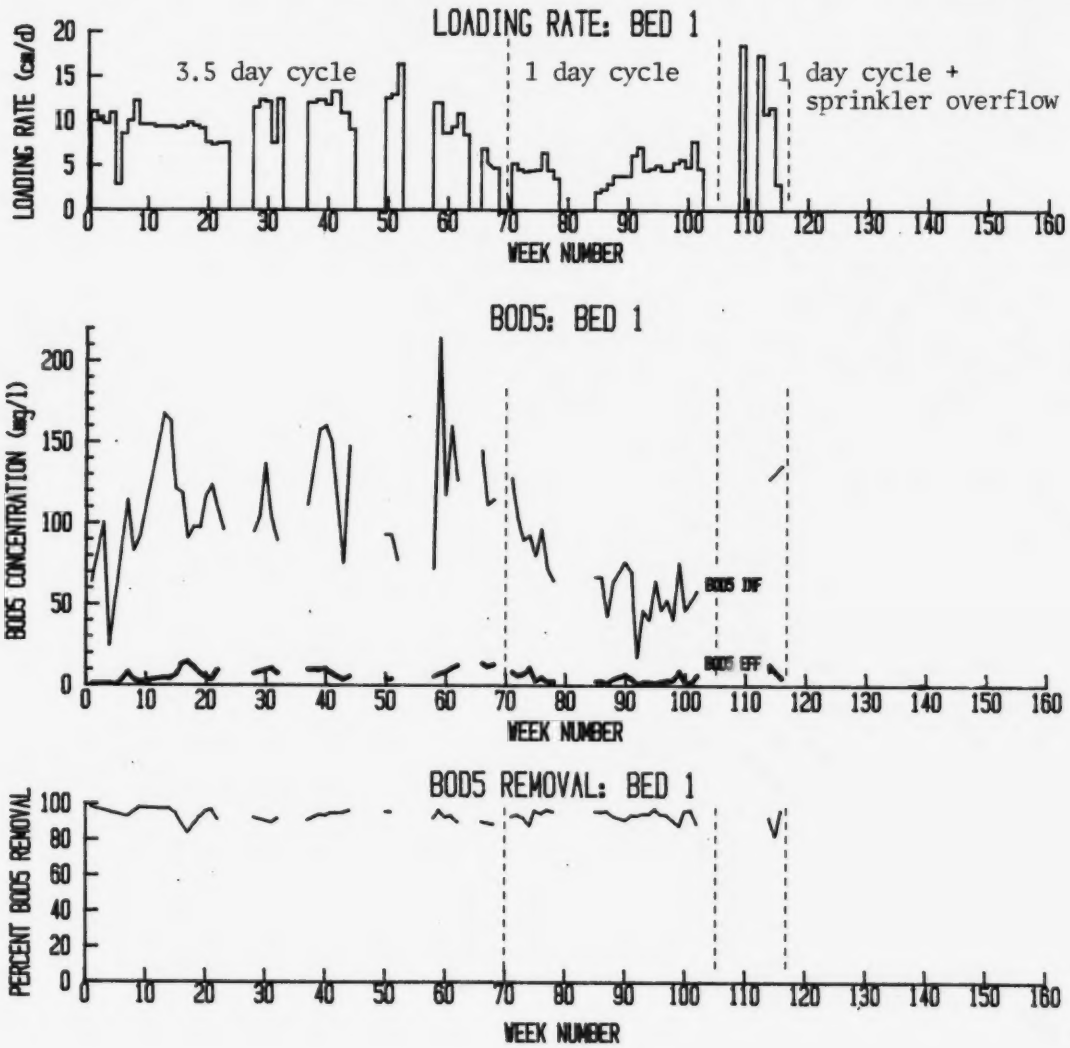

Figure 26. BOD analysis for bed 1

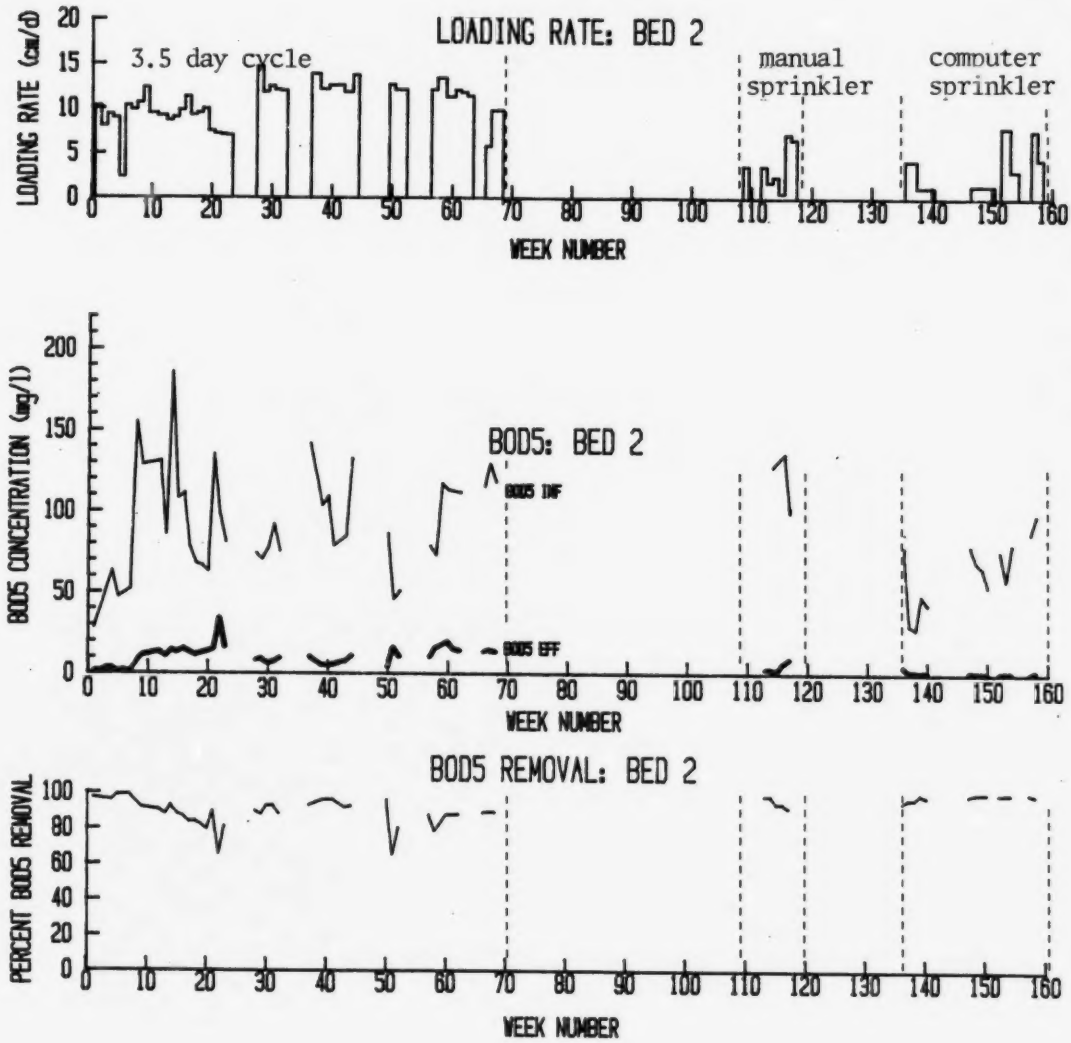

Figure 27. BOD analysis for bed 2.

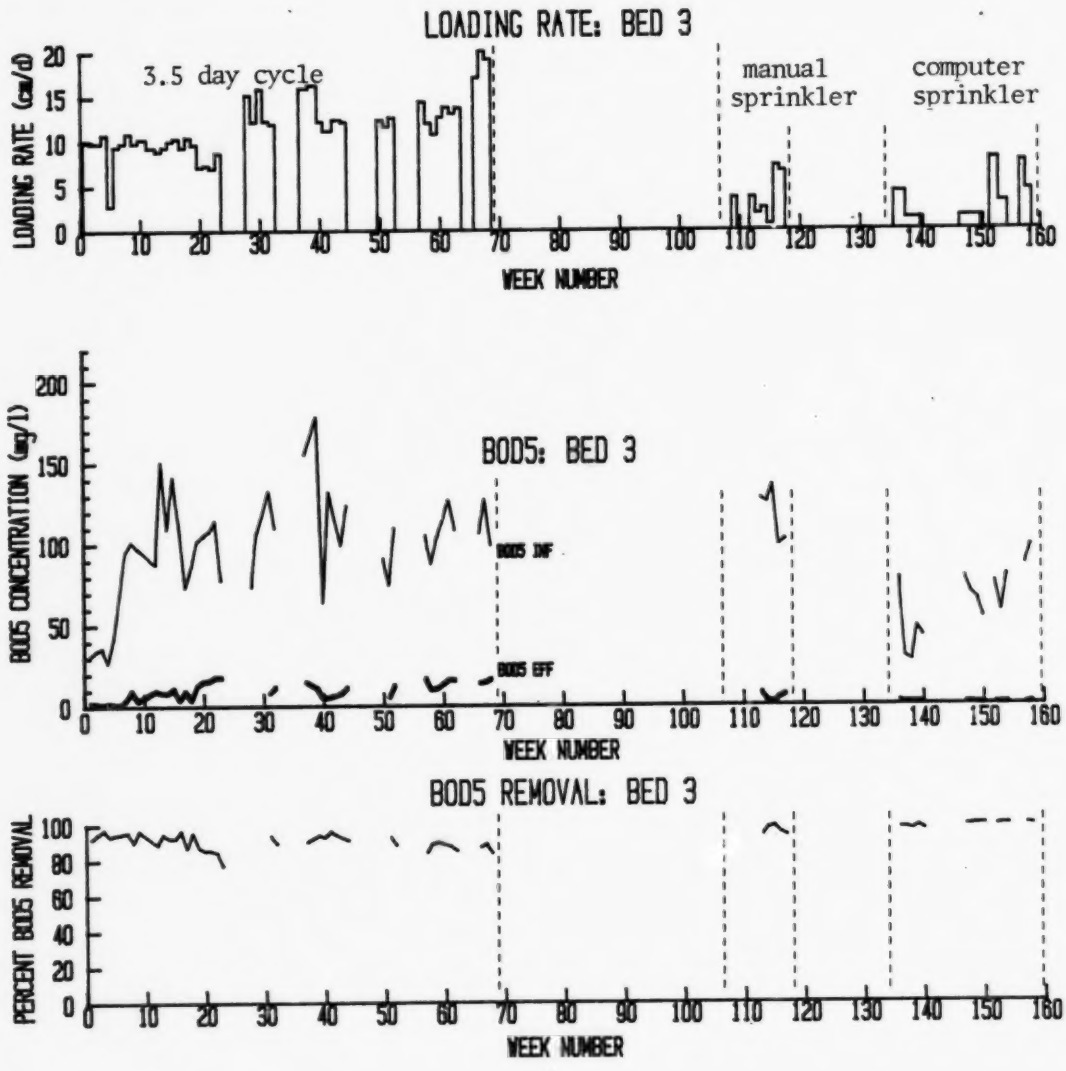

Figure 28. BOD analysis for bed 3.

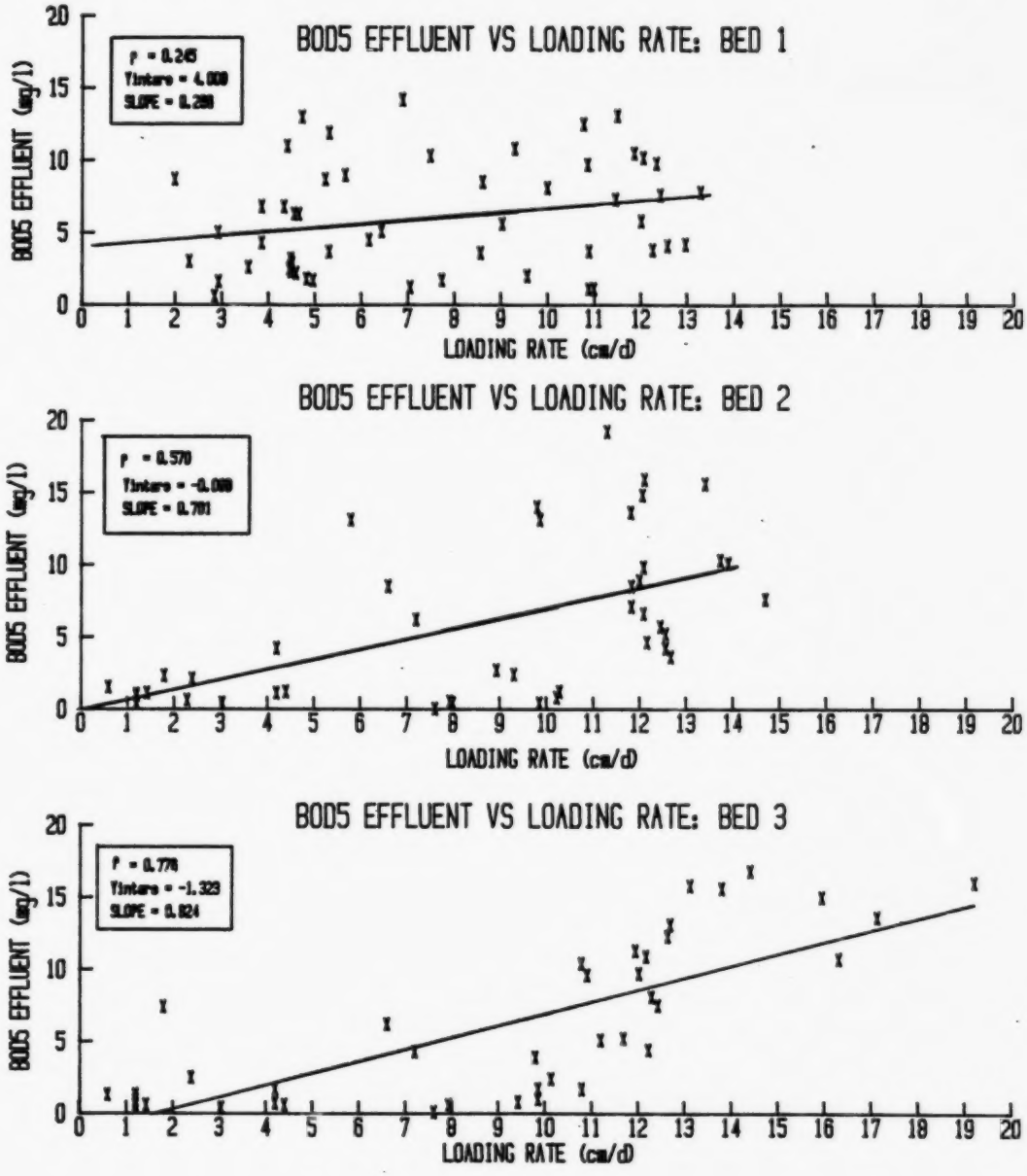
BOD5 EFFLUENT VS LOADING RATE: BED 1
BOD5 EFFLUENT (mg/l)
LOADING RATE (cm/d)
BOD5 EFFLUENT VS LOADING RATE: BED 2
BOD5 EFFLUENT (mg/l)
LOADING RATE (cm/d)
BOD5 EFFLUENT VS LOADING RATE: BED 3
BOD5 EFFLUENT (mg/l)
LOADING RATE (cm/d)

Figure 29. Effect of hydraulic loading rate on BOD removal.

was reduced below 5 cm/d, the average effluent BOD was 3 mg/l. The sprinkler system loading mode produced effluent BOD values consistantly below 1 mg/l.

SUSPENDED SOLIDS REMOVAL

The effluent suspended solids concentrations were higher than would be expected for an earth filtration system.(23) The results of the suspended solids analyses are shown in Figures 30, 31 and 32.

Analysis

Suspended solids concentrations followed the same removal pattern as that of BOD except that the influent values were lower and the effluent values were two to three mg/l greater. Inspection of the underdrain system revealed extensive biological slime growth and this was concluded to be the source of the particulate matter in the effluent. For systems discharging directly to the ground water, this would not be expected to occur. The concentration of effluent suspended solids was correlated with hydraulic loading rate as shown in Figure 33. This correlation, like that for the BOD's, gave one positive, one negative and one near-zero intercept and somewhat similar slopes.

THE SOLIDS MAT

The mat of solids that accumulates at the surface of a rapid infiltration bed serves several functions in the performance of the flood loaded system. The solids mat causes the decline in the infiltration rate with each loading and this establishes the reducing conditions needed for nitrogen removal. The mat also functions as a straining medium for the removal of particulate organics and inorganics.

A brief study was made to estimate the removal characteristics provided by the solids mat. Laboratory columns, 7.6 cm (3 in.) in diameter were set up, one with no media except a tightly stretched and supported fine nylon mesh and the other with the nylon mesh on top of 30 cm (12 in.) of earth material from the upper soil layer of bed 1 of the field project. The columns were loaded continuously with primary effluent until a solids mat was accumulated above the nylon mesh and the infiltration rate had been reduced to less than 50 cm/d (1.67 ft/day). The influent and effluent concentrations of the major pollutional constituents were measured for several consecutive loadings. The results are shown in Table 8.

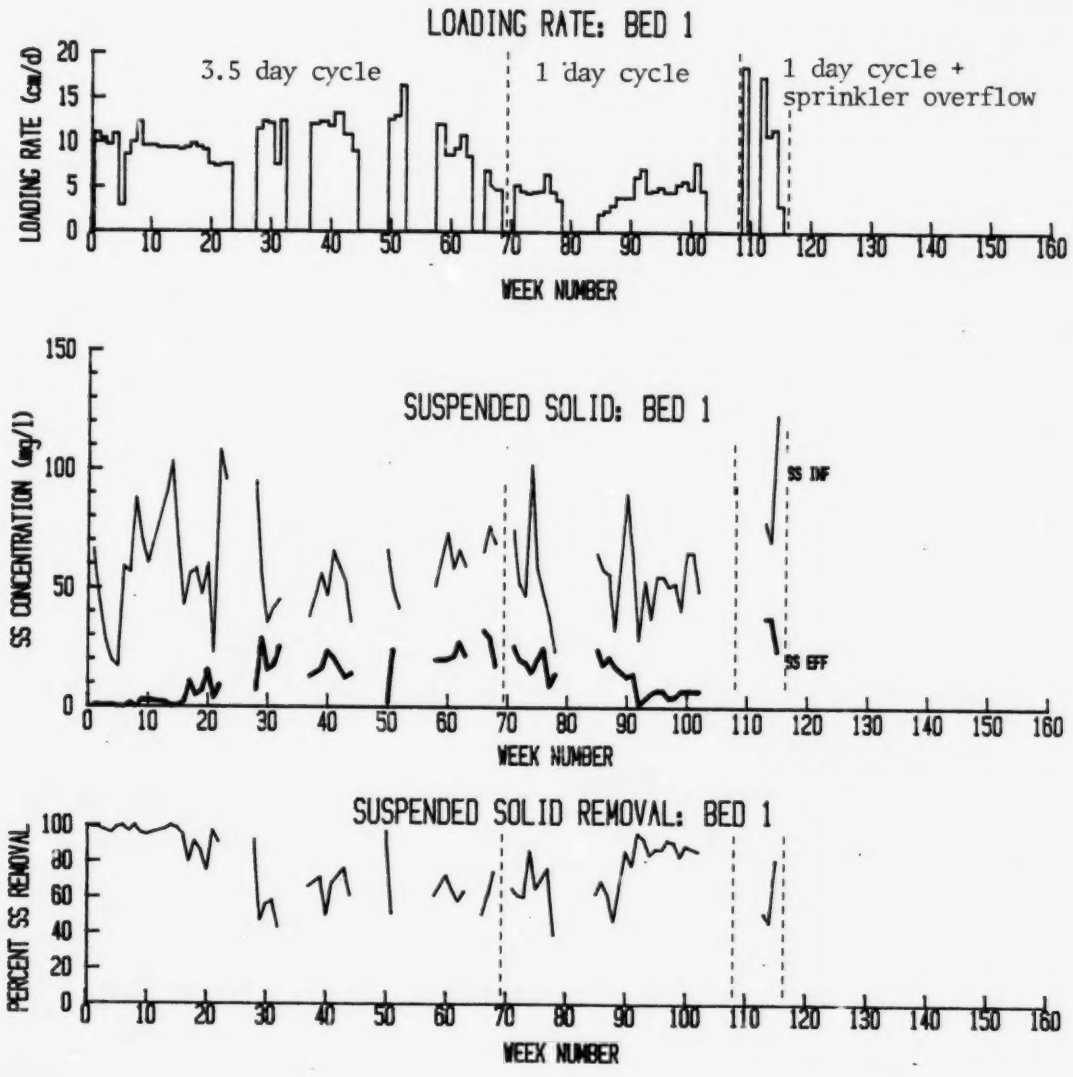

Figure 30. Suspended solids analysis for bed 1.

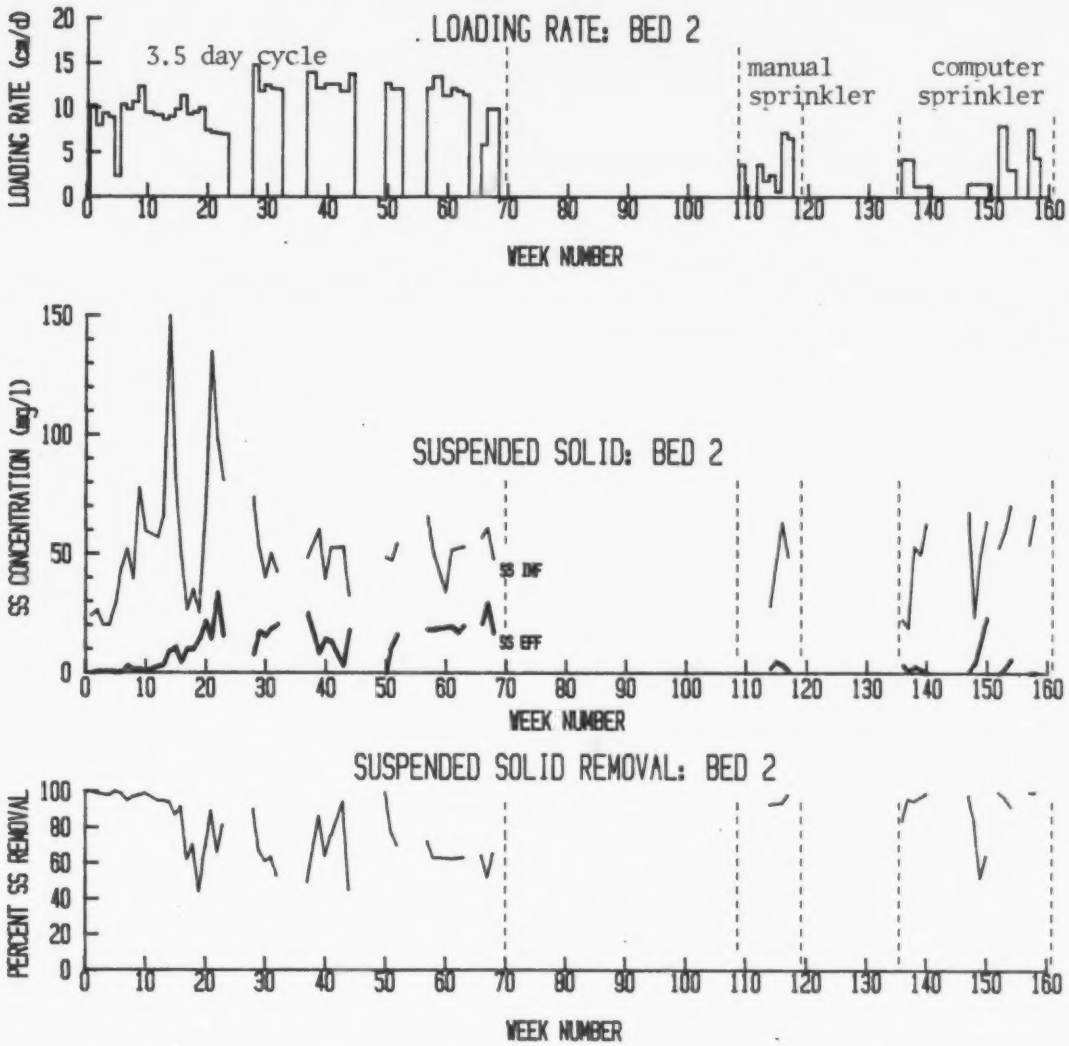

Figure 31. Suspended solids analysis for bed 2.

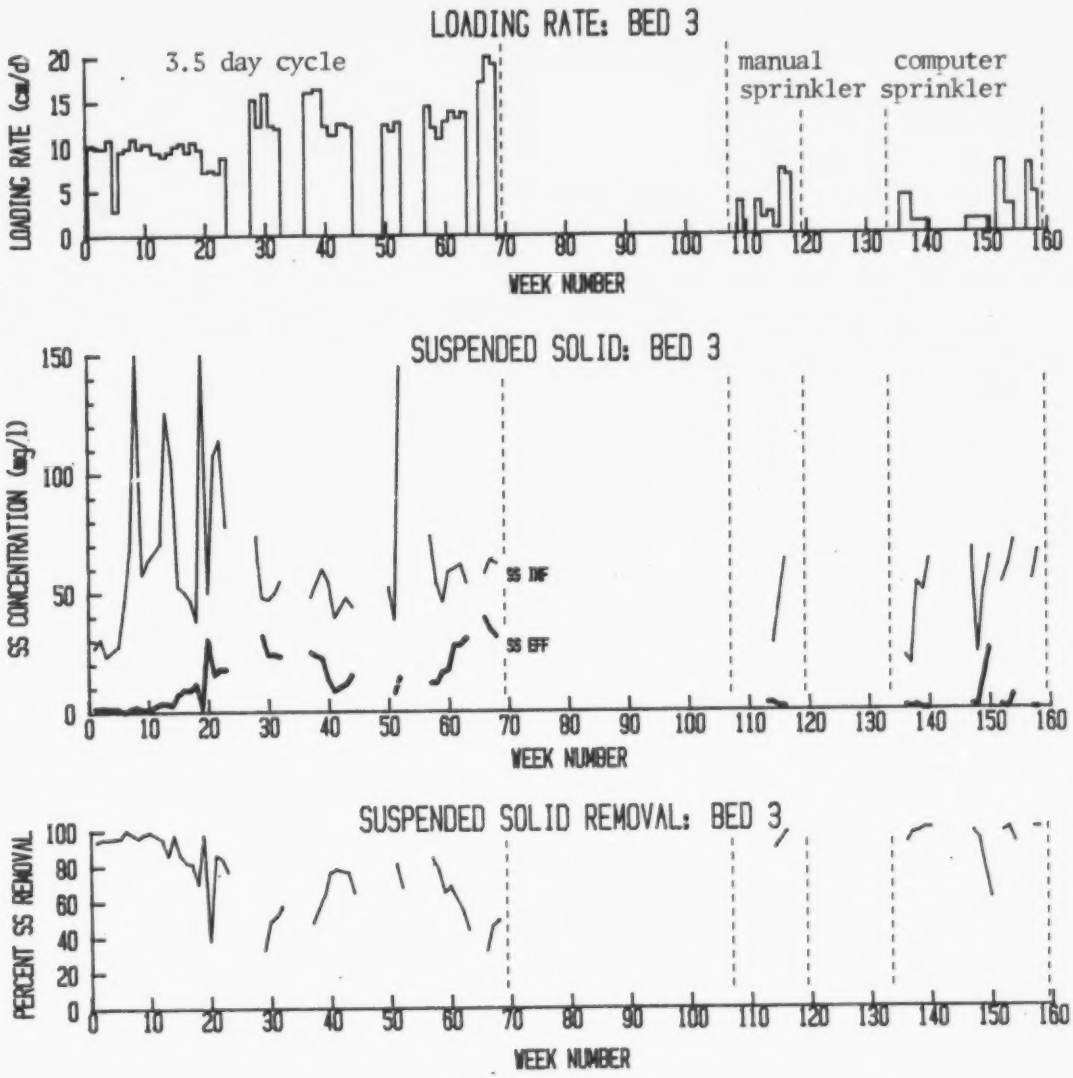

Figure 32. Suspended solids analysis for bed 3.

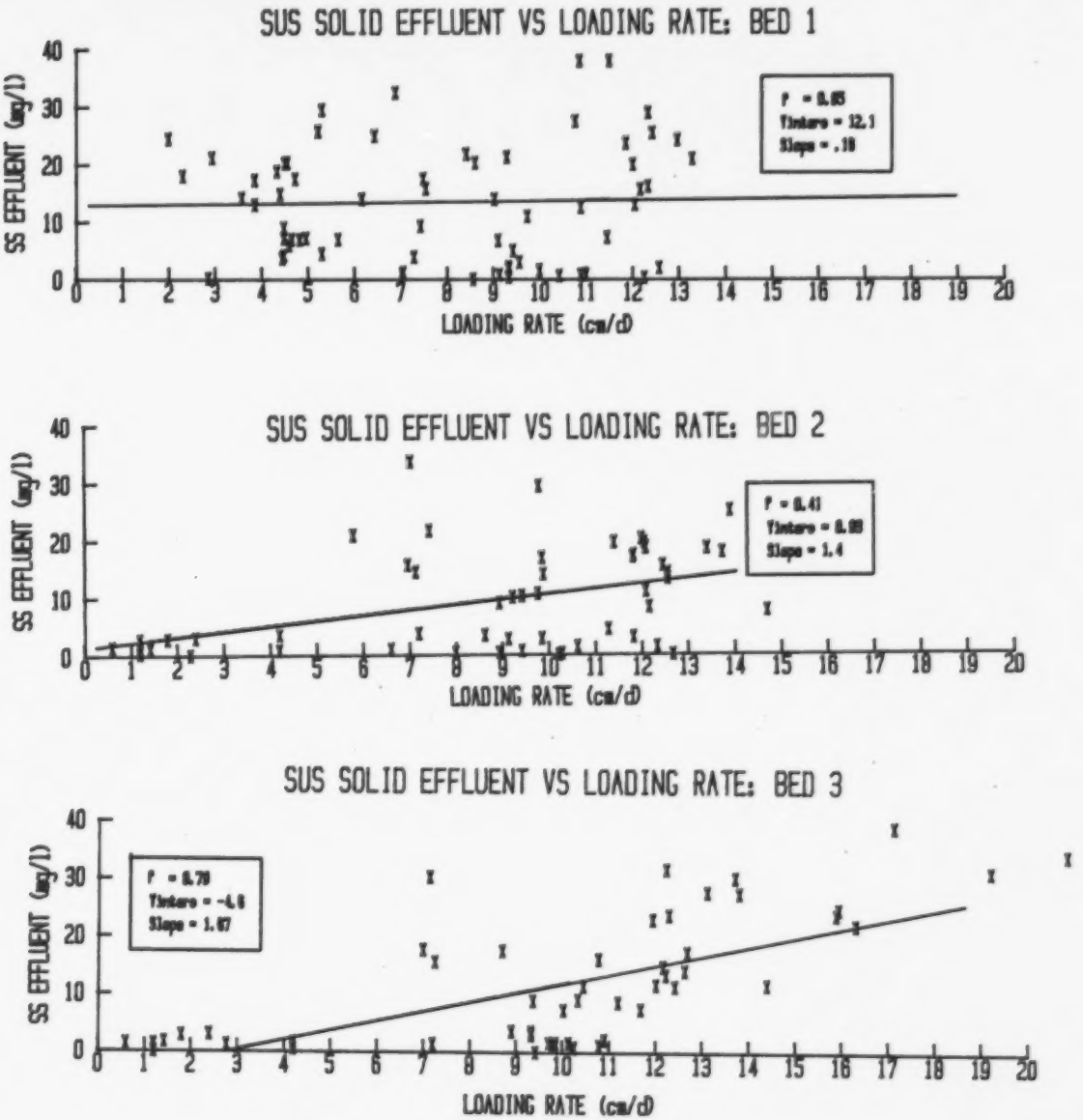

Figure 33. Effect of hydraulic loading rate on SS removal.

TABLE 8. LABORATORY COLUMN TESTS

Constituent	Nylon mesh % removed	Nylon mesh + soil % removed
Nitrogen		
Total Kjeldahl	12.0	95.5
Ammonia	-3.7	99.3
Organic	66.7	83.9
Total Nitrogen	10.7	82.2
Total Phosphorus-P	23.3	95.7
BOD	91.1	96.7

The solids mat (nylon mesh without soil) was found to have been responsible for a large portion of the BOD removal by straining, adsorption and assimilation. Organic nitrogen removals were high due to the particulate nature of this component. A significant amount of phosphorus was also adsorbed by the materials in the mat. Since a large portion of the influent BOD was removed in the surface mat and the nitrogen conversion and removal was found to take place deeper in the soil column, the importance of the soil organic matter in providing the carbon source for the biological nitrogen conversion reactions becomes apparent. Much of the soil organic matter results for scarification disking of the surface mat from previous loading sequences.

OPERATIONAL CONSIDERATIONS

One of the major considerations in the use of rapid infiltration beds with primary effluent is the potential of odors near the site. Odors were not a problem during the period of this research. Most of the time during the study, standing water, primary effluent, was present on the beds. Natural surface aeration was sufficient to prevent septic conditions and the ponding did not cause offensive odors.

The soils with high nutrient levels in the beds produced voluminous weed growth on the surface of the beds during the warmer months. Weed cutting was a necessary part of the system maintenance program for aesthetic reasons at the site. This was done about every six weeks in the summer, during the period when the beds were rested. Excessive algae growth occurred when the ambient air temperature was above 33°C (90°F) for extended periods of time. This condition caused clogging of the solids mat on the beds accompanied by greatly reduced infiltration rates. When this condition became excessive, it was necessary to rest the beds. This tended to cause shorter more frequent periods between restings of the beds in the summer than in the winter months.

Cold weather conditions had very little effect on the operation of the flood loaded beds. Temperatures as low as -23°C (-27°F) were encountered for short periods of time. Under the worst conditions, an ice layer several inches thick was formed on the beds and this seemed to have little effect on the overall functioning of the system. Problems were encountered with the sprinkler system during severe winter conditions. The system experienced

operating problems when the ambient air temperature went below freezing. Although the wastewater was warm enough to flow through the sprinkler nozzles in the normal fashion, some of the water would wet the outside of the sprinkler head housing. This water when frozen, would prevent the sprinkler head from turning and it would spray in the same position throughout the loading cycle.

The thin walled aluminum irrigation pipe was joined with connections having neopreme flap gaskets so that the pipe was water tight when pressurized and would drain the pipe at the joints when the pump was stopped between loadings. This prevented the freezing of the water within the pipe between loadings. It worked satisfactorily except when large snowstorms were encountered. The snow and ice surrounding the pipes would seal the joints causing the pipes to remain full of water and in some instances irrigation pipe repture was encountered. Spray loading systems must be used with some care in winter weather and provisions must be made for cold periods when the system cannot be operated.

SYSTEM OPTIMIZATION

Several conditions can be defined for the rapid infiltration system studied that resulted in an optimum operational range. Other rapid infiltration systems may have somewhat different optimum conditions because removal efficiencies for the important constituents are a function of the soil characteristics at the treatment site. It appeared that the top 15 to 30 cm (6 to 12 in.) of soil produced nearly all of the removals for the parameters of importance. The optimization can be defined in terms of an operating range that will produce the best combination of removals for four constituents; BOD, phosphorus, ammonia and nitrate.

Enhanced BOD removals were found to result primarily from lowering the hydraulic loading rate of the system. Phosphorus removals were found to be high when the mass loading rate on the long and short term were equivalent to or less than the mineralization rate of the soil material. In this study the value was found to be 3.0 Kg/Ha-d (0.3 gm/m^2-d). With an influent wastewater phosphorous concentration of approximately 7.5 mg/l, the hydraulic loading rate should not exceed about 4 cm/d (50 ft./yr., 1 gpd/ft^2). Ammonia leakage was also found to be reduced at low mass application rates. A value of 4 cm/day for the hydraulic loading rate was also found to be adventageous for improved nitrogen removal operating conditions.

While lowering loading rates enhanced the removals of these three parameters, there are two factors that provide the lower limit of hydraulic loading that can be used for an optimum system. One of these is system cost, but more importantly from the standpoint of performance is that nitrate removals require a high enough loading rate to produce saturated soil conditions. This is governed by the grain size distribution of the soil and the infiltration rate through the solids mat that forms at the surface of the beds. In this research, it was found that it required approximately 1000 Kg/ha (10 mg/cm^2, 0.022 lb/ft^2) of wastewater suspended solids captured at the surface to produce an infiltration rate low enough for the continuous

flooding over of the beds necessary for reducing conditions. This would require that the beds be loaded for more than seven weeks at a rate of 4 cm/day after each drying period before anoxic conditions could be fully reestablished. It was difficult to attain these conditions during the low loading rate phase of the flood loading studies on bed 1 and the sprinkler loading phase for beds 2 and 3. Two approaches could be used to improve the system operation. Resting periods, without scarification, should be short to prevent the drying out of the solids mat on the surface of the beds. New designs should use tighter, more organic soils with high cation exchange capacities to reduce inflitration rates and enhance the adsorption capacity for ammonia and phosphorus and allow somewhat higher hydraulic loading rates while maintaining saturated conditions.

RAPID INFILTRATION SYSTEM APPLICATIONS

Several different types of rapid infiltration process applications can be made and these are related to the method of applying the influent and drawing off the effluent from the beds. Most land treatment systems are designed to discharge directly to the groundwater, although the system used in this study with underdrain collection pipes and discharge to a surface stream may be a desirable design application for some situations. Flood loading offers the advantages of ease of operation and low energy consumption although sprinkler application may provide a better means for creating the soil moisture conditions required for nitrogen removal. Rapid infiltration systems loaded in the range of 5 to 7 cm/d (50-75 ft./yr.) can produce effluents with average BOD < 5 mg/l, P < 1 mg/l and total nitrogen < 10 mg/l under controlled operating conditions and values of approximately fifty percent of these levels with careful optimization. Coliform penetrations were a problem for the system studied since it had only about a three meter thickness of earth materials. For underdrained systems discharging to surface water, disinfection may be necessary.

This method of wastewater treatment is well suited for small communities of less than 10,000 population where low cost land with desirable soil characteristics is available.

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Appendix I

CHEMICAL AND ANALYTICAL RESULTS

LOADING RATE AND TEMPERATURE

Values shown for loading are based on readings from the totalizing flow meter on the influent pipe and the area of the bed. Effluent, grab sample temperatures are shown.

Week	Lo-1 cm/d	Lo-2 cm/d	Lo-3 cm/d	T-1 °C	T-2 °C	T-3 °C	Date
1	11.00	10.23	10.14	12.0	10.4	9.2	12/2/80
2	10.43	8.00	9.86	10.5	9.4	9.4	12/9/80
3	9.71	9.31	9.86	10.8	9.4	9.4	12/16/80
4	10.89	8.94	10.80	9.0	8.5	9.5	12/23/80
5	2.86	2.29	2.77	8.8	8.6	8.8	12/30/80
6	8.57	10.29	9.43	8.6	6.7	7.8	1/6/81
7	10.00	9.86	9.80	7.4	5.8	7.1	1/13/81
8	12.26	10.63	10.91	7.2	5.8	6.2	1/20/81
9	9.57	12.34	9.86	6.9	6.4	6.0	1/27/81
10	9.57	9.43	10.26	7.2	5.1	6.4	2/2/81
11	-	-	-	-	-	-	2/9/81
12	9.34	9.14	9.34	-	6.6	7.5	2/17/81
13	9.34	8.63	8.91	7.2	6.8	8.0	2/24/81
14	9.34	8.94	9.34	7.8	7.6	7.5	3/3/81
15	9.14	9.77	10.03	8.1	7.8	7.5	3/10/81
16	9.34	11.29	10.34	8.6	8.2	8.0	3/17/81
17	9.74	9.23	9.37	9.0	9.4	7.9	3/24/81
18	9.43	9.43	10.46	9.0	10.0	10.5	3/31/81
19	9.11	9.89	9.71	9.0	10.1	10.5	4/7/81
20	7.54	7.43	7.14	10.6	11.8	12.0	4/14/81
21	7.29	7.14	7.26	11.8	12.6	13.0	4/21/81
22	7.43	7.03	7.00	12.8	13.4	13.0	4/28/81
23	7.51	6.97	8.71	14.0	14.1	14.2	5/5/81
	Rest and scarify.						
28	11.46	14.71	15.23	15.0	16.0	18.0	6/9/81
29	12.34	11.83	12.23	18.0	16.5	18.0	6/16/81
30	12.17	12.46	15.89	20.5	19.4	20.0	6/23/81
31	7.49	12.09	12.29	20.0	20.0	19.6	6/30/81
32	12.43	12.00	11.94	21.0	20.0	20.5	7/7/81
	Rest and scarify.						
37	12.06	13.91	15.94	20.5	20.5	21.0	8/11/81
38	Sampling manhole flooded.						8/17/81
39	12.34	12.17	16.31	20.5	20.0	20.6	8/25/81
40	11.86	12.57	12.23	17.0	16.0	16.0	9/1/81
41	13.29	12.57	11.20	15.0	16.5	16.0	9/8/81
42	Sampling manhole flooded.						9/15/81
43	10.83	11.83	12.43	-	-	-	9/22/81
44	9.03	13.74	12.17	-	-	-	9/29/81

LOADING RATE AND TEMPERATURE (continued)

Week	Lo-1 cm/d	Lo-2 cm/d	Lo-3 cm/d	T-1 °C	T-2 °C	T-3 °C	Date
50	12.58	12.68	12.36	13.1	12.4	11.8	11/17/81
51	12.97	12.10	11.69	11.5	10.5	11.0	11/24/81
52	16.37	-	12.64	8.9	8.7	9.6	12/1/81
	Resting caused by effluent pump malfunction.						
57	-	12.09	14.41	-	6.2	6.6	1/5/82
58	12.01	13.41	12.02	6.7	5.6	6.0	1/12/82
59	-	-	10.78	-	-	5.5	1/18/82
60	8.61	11.29	12.69	5.8	6.0	6.0	1/25/82
61	9.30	12.06	13.80	5.0	4.6	5.0	2/1/82
62	10.77	11.81	13.11	4.9	5.0	5.3	2/8/82
63	8.42	11.41	13.71	5.9	5.8	6.4	2/15/82
	Resting.						
66	6.89	5.80	17.12	7.3	7.5	8.1	3/8/82
67	5.31	9.80	20.80	7.6	8.3	10.2	3/15/82
68	4.73	9.86	19.20	7.8	8.2	9.5	3/22/82
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.						
71	5.23			9.2			4/12/82
72	4.56			8.8			4/19/82
73	4.34			9.7			4/26/82
74	4.41			8.9			5/3/82
75	4.51			8.7			5/10/82
76	6.44			10.2			5/17/82
77	4.49			10.3			5/24/82
78	3.58			12.0			5/31/82
	Resting.						
85	2.00			16.5			7/19/82
86	2.31			16.9			7/26/82
87	2.94			17.5			8/2/82
88	3.86			17.5			8/9/82
89	-			-			8/16/82
90	3.86			17.6			8/23/82
91	6.17			18.5			8/30/82
92	7.06			18.2			9/7/82
93	4.46			17.3			9/13/82
94	4.60			17.4			9/20/82
95	4.97			16.8			9/27/82
96	4.49			15.9			10/4/82
97	4.49			15.3			10/11/82
98	5.31			14.7			10/18/82
99	5.66			15.1			10/25/82
100	4.83			13.5			11/1/82
101	7.74			12.4			11/8/82
102	4.66			11.6			11/15/82
	Flow values for beds 2 and 3 were determined from the amount of time that the spray pumps were on and the flow rate recorded from the spray system flow meters.						

LOADING RATE AND TEMPERATURE (continued)

Week	Lo-1 cm/d	Lo-2 cm/d	Lo-3 cm/d	T-1 °C	T-2 °C	T-3 °C	Date
	Beds 2 and 3 manually sprinkler loaded from week 109						
109	18.57	3.61	3.61	-	7.8	7.8	1/7/83
	Not loaded						
112	17.43	3.61	3.61	6.4	4.6	6.0	1/24/83
113	10.86	1.81	1.80	6.1	5.8	5.8	2/1/83
114	11.50	2.40	2.40	6.1	6.0	6.5	2/10/83
115	2.93	0.60	0.60	7.8	7.2	7.2	2/17/83
116	-	7.21	7.21	-	-	-	2/24/83
117	-	6.61	6.61	-	-	-	2/28/83
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.						
136		4.21	4.21		16.4	16.4	7/14/83
137		4.21	4.21		17.8	17.8	7/21/83
138		1.20	1.20		18.6	18.6	7/28/83
139		1.20	1.20		-	-	8/4/83
140		1.20	1.20		15.8	15.8	8/10/83
	Beds resting, pipe replacement.						
147		1.43	1.43		15.8	15.8	9/29/83
148		-	-		17.8	17.8	10/6/83
149		-	-		17.0	17.0	10/12/83
150		-	-		-	-	10/18/83
151	Beds resting, instrument problem.						10/25/83
152		7.94	7.94		-	-	11/2/83
153		-	-		12.0	12.0	11/11/83
154		3.05	3.05		-	-	11/17/83
	Beds resting, instrument problem.						
157		7.62	7.62		7.5	7.5	12/8/83
158		4.41	4.41		5.2	5.2	12/13/83

TOTAL NITROGEN

Values shown are flow weighted means based on eight determinations of concentration and flow for each point for each week with flow weighted means determined from a computer program.

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	27.10	17.60	20.45	16.16	25.28	20.06	41	(-)	2
2	22.30	20.70	19.00	12.79	14.43	9.47	43	30	50
3	-	19.10	18.50	10.00	13.06	11.15	-	0	40
4	14.46	17.50	18.10	10.01	10.66	10.59	31	39	42
5	22.67	18.00	18.80	12.48	15.06	19.98	45	17	(-)
6	19.10	24.00	19.80	14.76	15.53	14.07	27	35	39
7	27.59	22.16	35.06	9.55	15.55	11.88	57	30	67
8	-	-	-	10.23	9.29	11.57	-	-	-
9	46.23	37.64	35.51	9.59	8.13	9.18	79	79	74
10	48.97	41.22	40.96	11.01	8.45	10.45	79	80	75
11	-	-	-	-	-	-	-	-	-
12	-	36.85	38.20	-	-	-	-	-	-
13	-	31.44	37.53	-	-	-	-	-	-
14	27.64	-	-	7.23	6.46	-	74	-	-
15	37.18	29.37	26.08	6.07	6.24	7.54	84	79	70
16	-	29.22	32.62	6.31	6.63	6.79	-	72	79
17	26.84	22.91	26.18	6.01	6.96	8.09	78	70	69
18	28.09	27.77	28.29	5.59	8.55	7.81	80	69	73
19	31.81	28.85	29.03	5.99	7.06	7.78	81	75	73
20	31.49	29.31	27.36	4.58	8.14	7.51	76	72	73
21	30.24	27.79	31.18	5.04	8.92	8.79	83	68	72
22	20.24	25.33	36.67	5.27	7.09	8.33	74	77	77
23	22.61	28.84	26.54	5.60	9.01	8.76	75	69	67
	Rest and scarify.								
28	18.78	18.21	18.60	-	16.48	29.93	-	10	(-)
29	19.16	19.69	20.80	12.01	10.97	12.92	33	44	38
30	22.04	21.73	21.57	8.22	8.69	11.92	63	60	45
31	18.00	18.68	19.91	6.30	7.66	9.69	65	59	52
32	18.13	18.40	18.97	5.62	6.36	8.37	69	66	56
	Rest and scarify.								
37	21.72	24.76	19.58	7.81	9.01	10.21	64	64	48
38	Sampling manhole flooded.								
39	19.17	17.95	20.48	5.75	8.31	8.82	70	54	57
40	23.53	23.01	21.37	5.41	7.35	9.16	77	68	57
41	17.20	16.41	15.96	5.64	6.95	7.49	67	58	53
42	Sampling manhole flooded.								
43	-	-	-	-	-	-	-	-	-
44	17.79	16.94	18.72	4.48	5.95	5.78	75	65	69
	Rest and scarify.								

TOTAL NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
50	15.48	17.60	16.79	12.90	12.43	17.29	17	32	(-)
51	19.32	27.26	15.83	6.36	9.26	8.64	63	66	54
52	21.47	-	21.77	7.75	-	7.83	64	-	64
	Resting caused by effluent pump malfunction.								
57	-	19.73	21.94	-	7.84	15.99	-	47	39
58	24.46	24.70	20.86	10.60	12.49	9.26	57	50	56
59	-	-	25.22	-	-	10.71	-	-	59
60	29.68	25.38	26.73	9.54	11.26	9.32	68	56	65
61	35.39	28.18	21.56	10.88	13.36	11.48	68	53	47
62	33.93	28.45	28.59	11.25	11.66	10.61	67	59	63
63	27.92	28.72	31.29	10.59	11.79	12.36	67	59	63
	Resting.								
66	39.33	34.11	33.86	18.33	13.19	19.16	52	61	43
67	30.17	29.28	28.15	14.79	13.93	11.24	51	53	60
68	29.55	28.92	29.05	11.74	13.40	13.29	60	53	54
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	32.10			23.89			26		
72	40.04			19.56			50		
73	29.64			18.88			36		
74	38.33			13.06			66		
75	25.44			10.80			58		
76	27.19			10.07			63		
77	31.79			9.98			69		
78	16.00			9.13			43		
	Resting.								
85	21.24			8.16			62		
86	16.84			6.80			60		
87	18.01			8.87			48		
88	15.60			8.63			45		
89	-			-			-		
90	24.14			11.91			51		
91	18.81			9.67			47		
92	22.24			11.72			47		
93	26.28			7.66			71		
94	22.09			8.36			62		
95	19.38			8.40			57		
96	22.74			7.05			69		
97	29.06			10.46			64		
98	22.69			10.63			59		
99	18.49			7.64			68		
100	29.39			9.40			57		
101	26.41			9.00			66		
102	29.22			6.49			78		
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109.								

TOTAL NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
	Beds 2 and 3 manually sprinkler loaded from week 109.								
109	17.62	17.62	17.62	5.01	22.05	71.60	72	(-)	(-)
	Not loaded								
112	30.04	20.94	20.94	7.89	12.97	13.25	74	38	37
113	36.23	36.23	36.23	7.42	13.56	14.54	80	63	60
114	31.61	31.61	31.61	7.98	12.14	13.05	74	62	59
115	-	-	-	6.24	11.73	9.26	-	-	-
116	-	30.02	30.02	-	11.01	9.74	-	63	68
117	-	33.08	33.08	-	10.36	9.46	-	69	71
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		9.60	9.60		17.12	17.12		(-)	(-)
137		14.93	14.93		16.58	16.41		(-)	(-)
138		25.11	25.11		16.76	9.84		33	61
139		23.60	23.60		15.62	9.12		34	61
140		17.26	17.26		14.57	6.86		16	60
	Beds resting, pipe replacement.								
147		28.49	28.49		17.01	12.52		40	56
148		22.49	22.49		18.19	15.15		19	33
149		32.88	32.88		14.40	12.27		56	63
150		26.81	26.81		12.82	11.45		52	57
151	Beds resting, instrument problem.								
152		14.00	14.00		9.03	8.23		36	41
153		23.44	23.44		11.58	11.91		42	46
154		25.44	25.44		11.90	12.90		53	49
	Beds resting, instrument problem.								
157		23.28	23.28		9.42	8.34		60	64
158		22.66	22.66		9.06	9.72		60	57

KJELDAHL NITROGEN

Values shown are flow weighted means based on eight determinaions of concentration and flow for each point for each week with flow weighted means determined from a computer program.

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	25.70	15.00	19.00	1.06	1.48	1.36	96	90	93
2	20.50	18.90	17.20	1.68	2.81	1.31	91	87	93
3	20.20	17.00	16.30	1.78	2.06	1.73	91	88	89
4	13.80	16.50	15.70	1.91	2.01	1.53	87	88	90
5	20.62	15.40	17.00	0.78	2.13	0.98	87	88	90
6	16.90	21.50	17.60	1.55	1.47	1.86	91	93	89
7	26.00	20.60	34.00	2.82	2.31	1.61	89	89	95
8	29.19	22.60	36.20	4.02	3.42	3.11	87	84	92
9	45.09	35.89	34.88	3.97	4.52	4.22	91	87	88
10	46.72	39.03	39.03	4.76	7.53	3.61	90	89	91
11	-	-	-	-	-	-	-	-	-
12	-	36.18	37.62	-	-	-	-	-	-
13	23.89	29.64	36.86	-	-	-	-	-	-
14	27.14	-	-	4.17	5.25	-	85	-	-
15	36.48	27.47	25.68	4.06	5.28	5.93	89	81	77
16	24.29	28.42	32.12	4.20	5.64	5.76	83	80	82
17	26.24	21.71	25.28	4.95	5.96	6.78	81	73	73
18	27.53	27.05	27.72	4.43	7.75	7.01	84	71	75
19	31.31	27.36	28.49	5.03	6.75	7.47	84	75	74
20	31.00	17.70	18.10	3.61	7.79	7.16	88	73	74
21	29.90	27.40	30.50	4.21	8.51	8.38	86	69	73
22	20.00	24.60	36.10	4.89	6.68	8.14	76	73	77
23	21.73	28.00	25.68	5.36	8.82	8.63	75	69	66
	Rest and scarify.								
28	17.60	17.70	18.10	6.41	7.92	12.83	64	55	29
29	18.90	19.30	20.60	7.91	7.77	11.11	58	60	46
30	21.60	21.40	21.20	7.68	7.85	9.89	65	63	53
31	17.50	18.10	19.50	5.60	6.80	8.92	68	63	54
32	17.80	17.80	18.60	5.20	5.88	7.79	71	67	58
	Rest and scarify.								
37	21.40	24.60	19.40	4.71	7.30	6.11	78	70	69
38	Sampling manhole flooded.								
39	18.70	17.70	20.30	5.05	6.21	5.66	73	65	72
40	23.40	22.80	21.10	5.22	5.72	5.04	78	75	76
41	17.09	16.33	15.80	4.36	5.32	3.79	75	67	76
42	Sampling manhole flooded.								
43	16.22	17.31	16.41	3.54	4.62	3.71	78	73	77
44	17.67	16.73	18.71	3.88	4.72	4.02	78	72	78
	Rest and scarify.								

KJELDAHL NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
50	15.00	16.93	16.24	5.10	4.56	4.27	66	73	74
51	19.19	27.04	15.08	4.99	5.58	3.67	74	79	76
52	21.03	-	21.39	5.47	-	4.22	74	-	80
	Resting caused by effluent pump malfunction.								
57	-	19.12	21.68	-	5.21	8.02	-	73	63
58	23.92	24.25	20.24	7.28	10.06	6.70	70	59	67
59	-	-	25.08	-	-	7.95	-	-	68
60	29.54	25.24	26.59	6.99	8.90	7.21	76	65	73
61	35.29	28.02	21.50	8.40	11.00	9.67	76	61	55
62	33.81	28.28	28.44	8.90	9.56	8.99	74	66	68
63	27.76	28.54	31.14	8.27	9.66	10.44	70	66	66
	Resting.								
66	39.17	33.94	33.77	13.00	10.29	14.72	67	70	56
67	30.01	29.12	28.04	10.15	11.49	9.57	66	61	66
68	29.36	28.70	28.64	9.00	11.11	11.47	69	61	60
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	31.76			12.36			61		
72	39.84			11.16			72		
73	29.45			11.27			62		
74	38.14			9.30			76		
75	25.13			7.06			72		
76	27.00			6.88			75		
77	31.23			6.98			78		
78	14.57			6.36			56		
	Resting.								
85	21.24			3.62			83		
86	16.46			3.91			76		
87	17.00			5.88			65		
88	15.13			5.69			62		
89	-			-			-		
90	23.90			6.31			74		
91	18.62			4.31			77		
92	21.75			4.60			79		
93	26.18			4.09			84		
94	21.42			7.02			67		
95	18.75			3.38			82		
96	22.52			2.63			88		
97	28.38			4.47			84		
98	22.42			3.86			83		
99	18.32			3.34			82		
100	29.18			3.93			87		
101	26.25			3.12			88		
102	28.76			2.76			90		
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109.								

KJELDAHL NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
	Beds 2 and 3 manually sprinkler loaded from week 109.								
109	17.20	17.20	17.20	3.10	1.13	0.85	82	93	95
	Not loaded								
112	29.62	2.030	20.30	7.51	1.87	1.64	75	91	92
113	36.10	36.10	36.10	7.15	1.72	1.76	80	95	95
114	31.50	31.50	31.50	7.70	1.68	1.03	73	95	96
115	-	-	-	5.30	1.17	0.83	-	-	-
116	-	29.90	29.90	-	4.52	2.73	-	85	91
117	-	32.96	32.96	-	4.96	2.69	-	85	92
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		9.58	9.580		1.52	0.00		84	100
137		14.91	14.91		0.74	0.00		95	100
138		25.09	25.09		0.86	0.61		97	98
139		23.58	23.58		0.94	0.76		97	97
140		17.24	17.24		0.46	0.42		97	98
	Beds resting, pipe replacement.								
147		28.16	28.16		0.68	0.47		98	98
148		22.16	22.16		0.43	0.30		98	99
149		32.74	32.74		0.46	0.33		99	99
150		26.58	26.58		0.54	2.62		98	90
151	Beds resting, instrument problem.								
152		14.00	14.00		1.20	0.88		91	94
153		23.44	23.44		0.37	0.72		98	97
154		25.44	25.44		1.06	1.79		96	93
	Beds resting, instrument problem.								
157		23.28	23.28		0.66	0.80		97	97
158		22.64	22.94		3.09	3.42		86	85

AMMONIA NITROGEN

Values shown are flow weighted means based on eight determinations of concentration and flow for each point for each week with flow weighted means determined from a computer program.

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	10.60	5.28	8.08	0.15	0.17	0.17	99	97	98
2	11.85	12.60	12.44	0.23	0.92	0.33	98	93	97
3	11.00	9.50	12.10	0.62	0.92	0.67	94	90	95
4	7.60	12.50	9.30	0.92	1.54	0.66	87	88	93
5	9.88	9.96	12.26	0.57	0.82	0.48	94	92	96
6	14.10	15.10	16.40	0.69	0.99	0.43	95	95	97
7	24.07	22.92	26.02	1.23	1.71	1.26	95	93	95
8	-	-	29.34	2.20	2.00	1.36	-	-	96
9	24.00	24.41	20.92	2.46	3.11	1.94	90	88	90
10	30.27	30.19	30.46	3.60	3.21	2.98	88	89	90
11	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-
13	23.04	18.48	19.81	3.51	3.96	2.80	85	79	85
14	19.80	16.74	23.96	3.21	3.06	2.88	84	81	88
15	16.04	21.00	19.40	1.95	3.96	4.92	88	81	76
16	16.84	17.66	19.46	2.91	4.17	4.21	83	76	78
17	19.72	15.01	16.27	2.94	4.07	6.35	86	73	61
18	19.11	18.78	20.16	3.06	5.74	5.80	84	70	71
19	21.86	20.83	19.61	3.97	5.12	6.05	82	75	69
20	21.46	18.92	24.19	2.62	5.22	6.10	88	72	75
21	16.11	10.28	12.30	2.67	3.91	6.99	84	71	43
22	13.85	15.82	24.71	2.71	4.69	7.11	80	70	71
23	16.81	19.58	18.45	4.98	6.80	7.16	70	65	61
	Rest and scarify.								
28	12.90	12.50	12.60	5.21	7.95	11.26	60	36	11
29	14.70	14.00	15.20	5.90	6.02	9.17	60	57	40
30	12.60	13.70	13.60	5.74	6.21	7.88	55	55	42
31	14.20	13.20	13.90	4.76	5.97	7.80	67	55	45
32	12.00	13.30	13.20	4.62	5.41	7.29	42	59	45
	Rest and scarify.								
37	14.00	14.30	12.70	4.06	5.30	4.88	71	63	62
38	Sampling manhole flooded.								
39	13.10	14.70	14.80	4.50	4.72	5.21	65	68	65
40	16.30	16.50	15.70	4.87	5.35	4.23	70	68	73
41	11.80	12.70	12.90	4.36	5.32	3.79	64	58	71
42	Sampling manhole flooded.								
43	12.58	13.86	12.99	3.52	4.12	3.22	72	70	75
44	12.88	12.27	13.74	3.29	4.17	3.50	75	66	75
	Rest and scarify.								

AMMONIA NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
50	11.87	14.47	11.49	3.70	3.63	3.16	69	75	73
51	13.83	13.94	12.76	4.54	4.75	3.37	67	66	74
52	13.70	-	13.87	4.81	-	3.59	64	-	74
	Resting caused by effluent pump malfunction.								
57	-	12.65	13.21	-	7.10	4.83	-	44	64
58	14.30	13.67	14.30	6.64	8.92	5.76	54	35	60
59	-	-	23.05	-	-	7.95	-	-	68
60	16.66	20.66	21.25	6.52	8.10	6.60	61	61	69
61	22.00	19.99	16.62	7.75	9.53	8.89	64	52	47
62	21.38	20.21	10.72	8.34	9.07	8.81	61	55	18
63	21.04	20.43	21.62	7.94	9.04	10.01	62	56	54
	Resting.								
66	22.14	20.14	20.89	10.12	8.84	10.88	52	57	48
67	21.70	21.31	19.85	9.80	10.64	8.56	55	50	57
68	19.45	18.75	19.03	8.32	10.14	9.98	57	46	46
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	21.51			10.34			49		
72	17.78			8.53			52		
73	19.40			7.79			60		
74	19.91			6.59			67		
75	18.57			6.42			65		
76	12.08			6.31			48		
77	14.58			6.18			58		
78	10.36			6.16			41		
	Resting.								
85	10.76			3.23			70		
86	10.40			3.56			66		
87	9.75			5.43			44		
88	8.34			5.11			39		
89	-			-			-		
90	11.25			4.34			61		
91	14.11			4.31			67		
92	12.76			3.94			69		
93	15.42			3.75			76		
94	13.20			3.41			74		
95	14.66			2.63			82		
96	17.82			2.36			87		
97	16.34			2.38			85		
98	15.23			2.13			82		
99	10.32			1.87			86		
100	16.65			2.31			86		
101	18.17			2.10			88		
102	18.65			2.07			89		
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109.								

AMMONIA NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
	Beds 2 and 3 manually sprinkler loaded from week 109.								
109	17.32	17.32	17.32	1.96	0.96	0.55	88	95	97
	Not loaded								
112	22.21	15.37	15.37	6.05	0.77	0.43	73	95	97
113	22.35	22.35	22.35	6.64	1.11	1.00	70	95	96
114	22.87	22.87	22.87	7.11	1.03	0.49	68	96	98
115	14.98	14.98	14.98	5.31	0.54	0.35	65	96	98
116	-	18.46	18.46	-	3.46	1.81	-	81	90
117	-	21.17	21.17	-	3.85	1.90	-	82	91
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		9.08	9.08		1.01	0.13		90	99
137		16.95	16.95		1.14	0.25		93	97
138		16.83	16.83		0.13	0.13		99	99
139		17.23	17.23		0.32	0.05		98	99
140		14.81	14.81		0.00	0.00		100	100
	Beds resting, pipe replacement.								
147		21.33	21.33		0.33	0.21		99	99
148		16.49	16.49		0.36	0.21		98	99
149		13.76	13.76		0.30	0.20		98	99
150		19.01	19.01		0.57	0.37		97	98
151	Beds resting, instrument problem.								
152		5.98	5.98		0.35	0.55		94	91
153		19.13	19.13		0.05	0.29		100	99
154		21.03	21.03		0.60	1.80		97	95
	Beds resting, instrument problem.								
157		22.47	22.47		0.13	0.23		99	99
158		23.02	23.02		2.32	2.64		90	89

ORGANIC NITROGEN

Values shown are flow weighted means based on eight determinations of concentration and flow for each point for each week with flow weighted means determined from a computer program. Organic nitrogen concentration was computed from total Kjeldahl nitrogen minus ammonia nitrogen.

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	15.10	9.72	10.92	0.91	1.31	1.19	94	86	89
2	8.65	6.30	4.76	1.48	1.49	0.98	83	76	80
3	9.20	7.50	4.20	1.16	1.14	1.06	64	85	75
4	6.20	4.00	6.40	0.99	0.47	0.87	85	88	86
5	10.74	5.44	4.74	0.21	0.31	0.50	98	77	89
6	2.80	6.40	1.20	0.89	0.61	1.43	68	70	(-)
7	1.93	-	7.98	1.59	0.60	0.35	18	-	96
8	-	-	6.86	1.82	1.42	1.75	-	-	75
9	21.09	11.48	13.36	1.51	1.41	1.28	93	87	90
10	16.45	8.84	8.57	1.16	1.32	0.63	93	85	92
11	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-
13	0.85	11.16	17.05	-	-	-	-	-	-
14	7.34	-	-	0.96	2.19	-	87	-	-
15	20.44	6.47	6.28	2.11	1.32	1.01	90	80	84
16	7.45	10.76	12.66	1.29	1.47	1.55	83	86	88
17	6.52	6.70	9.01	2.01	1.89	0.53	69	72	94
18	8.42	8.27	7.56	1.37	2.01	1.21	84	76	84
19	9.45	7.13	8.88	1.04	1.63	1.44	89	77	84
20	9.54	9.48	3.01	0.99	2.57	1.06	89	73	67
21	13.80	17.12	18.20	1.54	1.97	1.57	75	62	72
22	6.15	8.78	11.39	2.17	2.01	1.03	65	77	91
23	4.82	8.42	7.23	0.38	2.02	1.47	92	76	80
	Rest and scarify.								
28	4.70	5.20	5.50	1.20	1.97	1.57	75	62	72
29	4.20	5.30	5.40	2.01	1.75	1.94	52	67	64
30	9.00	7.70	7.60	1.89	1.649	2.01	79	79	74
31	3.30	4.90	5.60	0.84	0.83	1.11	75	84	80
32	5.80	4.50	5.40	0.58	0.47	0.50	90	90	91
	Rest and scarify.								
37	7.40	10.30	6.70	0.65	2.00	1.23	91	80	82
38	Sampling manhole flooded.								
39	5.60	3.00	5.50	0.55	1.49	0.45	90	50	92
40	7.10	6.30	5.40	0.35	0.37	0.81	95	94	85
41	5.29	3.63	2.90	0.00	0.00	0.00	100	100	100

ORGANIC NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
42	Sampling manhole flooded.								
43	3.64	3.45	3.42	0.00	0.50	0.47	100	86	86
44	4.79	4.46	4.97	0.57	0.55	0.52	88	88	90
	Rest and scarify.								
50	3.13	2.46	4.75	1.40	0.93	1.11	55	62	77
51	5.36	13.10	2.32	0.45	0.83	0.30	94	94	87
52	7.33	-	7.52	0.66	-	0.63	91	-	92
	Resting caused by effluent pump malfunction.								
57	-	6.47	8.47	-	-	3.19	-	-	94
58	9.62	10.57	5.94	0.64	1.14	0.94	93	89	84
59	-	-	2.03	-	-	0.50	-	-	75
60	12.88	4.58	5.34	0.47	0.80	0.61	96	83	89
61	13.29	8.03	4.88	0.65	1.47	0.80	95	82	84
62	12.43	8.07	17.72	0.56	0.49	0.18	96	94	99
63	6.72	8.11	9.52	0.33	0.62	0.43	95	92	95
	Resting.								
66	17.03	13.53	12.88	2.88	1.45	3.84	83	89	70
67	8.31	7.81	8.19	0.35	0.85	1.01	96	89	88
68	9.91	9.95	9.61	0.68	0.97	1.49	93	91	85
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	10.25			1.42			86		
72	22.06			2.63			88		
73	10.05			3.48			65		
74	18.23			2.71			85		
75	6.56			0.65			90		
76	14.92			0.57			96		
77	16.65			0.80			95		
78	4.21			0.20			95		
	Resting.								
85	10.48			0.39			96		
86	6.06			0.35			94		
87	7.25			0.45			94		
88	6.79			0.58			92		
89	-			-			-		
90	12.65			1.97			84		
91	4.51			0.00			100		
92	8.99			0.66			93		
93	10.76			0.34			97		
94	8.22			3.61			84		
95	4.29			0.75			82		
96	4.70			0.27			94		
97	12.04			2.09			83		
98	7.19			1.73			82		
99	8.00			1.47			76		
100	12.53			1.62			76		
101	8.08			1.02			87		

ORGANIC NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
102	10.11			0.69			94		
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.								
109	-	-	-	1.14	0.17	0.30	-	-	-
	Not loaded								
112	7.41	4.93	4.93	1.46	1.10	1.21	80	78	76
113	13.75	13.75	13.75	0.51	0.61	0.76	96	96	95
114	6.56	8.63	8.63	0.59	0.65	0.54	91	93	94
115	-	-	-	0.59	0.63	0.48	-	-	-
116	-	11.44	11.44	-	1.06	0.92	-	91	92
117	-	11.79	11.79	-	1.11	0.79	-	91	93
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		0.50	0.50		0.51	-		(-)	-
137		0.00	0.00		0.51	-		(-)	-
138		8.26	8.26		0.73	0.48		91	94
139		6.35	6.35		0.62	0.71		90	89
140		2.44	2.44		0.46	0.42		81	83
	Beds resting, pipe replacement.								
147		6.83	6.83		0.35	0.26		95	96
148		5.76	5.76		0.13	0.09		98	98
149		18.98	18.98		0.16	0.13		99	99
150		7.57	7.57		-	2.25		-	70
151	Beds resting, instrument problem.								
152		8.02	8.02		0.85	0.33		89	96
153		4.31	4.31		0.32	0.43		93	90
154		4.41	4.41		0.46	0.71		90	90
	Beds resting, instrument problem.								
157		0.81	0.81		0.53	0.57		35	30
158		0.00	0.00		0.77	0.78		(-)	(-)

NITRATE NITROGEN

Values shown are flow weighted means based on eight determinations of concentration and flow for each point for each week with flow weighted means determined from a computer program.

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1 %R-2 %R-3
1	1.40	2.60	1.45	15.10	23.80	18.70	All values
2	1.80	1.80	1.80	11.11	12.12	8.16	increased
3	-	2.10	2.20	8.22	11.00	9.42	
4	0.66	1.00	2.40	8.10	8.65	9.06	
5	2.05	2.60	1.80	11.71	12.93	19.00	
6	2.20	2.50	2.20	13.21	14.06	12.21	
7	1.59	1.56	1.06	8.00	13.24	10.27	
8	-	-	-	6.21	5.87	8.46	
9	1.14	1.75	1.23	5.57	3.61	4.96	
10	2.25	2.19	1.93	6.25	3.42	6.84	
11	-	-	-	-	-	-	
12	-	0.67	0.58	6.00	1.56	3.89	
13	1.12	1.80	0.67	6.61	1.24	2.21	
14	0.50	0.42	0.42	3.06	1.21	1.94	
15	0.70	1.90	0.40	2.01	0.96	1.61	
16	0.94	0.80	0.50	2.11	0.99	1.03	
17	0.60	1.20	0.90	1.96	1.00	1.31	
18	0.56	0.72	0.57	1.16	1.03	0.80	
19	0.50	0.89	0.54	0.96	1.00	0.31	
20	0.49	0.91	0.16	0.93	0.91	0.35	
21	0.34	0.39	0.68	0.83	0.66	0.41	
22	0.24	0.73	0.57	0.38	0.41	0.19	
23	0.88	0.84	0.86	0.24	0.25	0.13	
	Rest and scarify.						
28	0.68	0.41	0.58	-	8.56	17.10	
29	0.26	0.39	0.20	4.10	3.20	1.81	
30	0.44	0.33	0.37	0.54	0.83	2.03	
31	0.50	0.58	0.41	0.62	0.86	0.77	
32	0.33	0.60	0.37	0.42	0.48	0.58	
	Rest and scarify.						
37	0.32	0.16	0.18	3.10	0.72	4.10	
38	Sampling manhole flooded.						
39	0.47	0.25	0.18	1.32	1.71	3.60	
40	0.13	0.21	0.27	0.70	2.10	3.16	
41	0.11	0.08	0.16	0.42	1.63	4.12	

NITRATE NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l
42	Sampling manhole flooded.					
43	0.12	0.21	0.18	0.59	1.29	3.70
44	0.12	0.21	0.10	0.60	1.23	1.76
	Rest and scarify.					
50	0.48	0.67	0.55	7.80	7.87	13.02
51	0.13	0.22	0.75	1.37	3.68	4.97
52	0.44	-	0.38	2.28	-	3.61
	Resting caused by effluent pump malfunction.					
57	-	0.61	0.26	-	2.63	7.97
58	0.54	0.45	0.62	3.32	2.43	2.56
59	-	-	0.14	-	-	2.76
60	0.14	0.14	0.14	2.55	2.36	2.11
61	0.10	0.16	0.06	2.48	2.36	1.79
62	0.12	0.17	0.15	2.35	2.10	1.62
63	0.16	0.18	0.15	2.32	2.13	1.92
	Resting.					
66	0.16	0.17	0.09	15.33	2.90	14.44
67	0.16	0.16	0.11	4.64	2.44	1.67
68	0.19	0.22	0.41	2.74	2.29	1.82
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.					
71	0.34			11.53		
72	0.20			8.40		
73	0.19			7.61		
74	0.19			3.76		
75	0.31			3.74		
76	0.19			3.19		
77	0.56			3.00		
78	1.43			2.77		
	Resting.					
85	0.00			4.54		
86	0.36			2.89		
87	1.01			2.99		
88	0.46			2.94		
89	-			-		
90	0.24			5.60		
91	0.19			5.36		
92	0.49			7.12		
93	0.10			3.57		
94	0.67			1.34		
95	0.43			5.02		
96	0.22			4.42		
97	0.68			5.99		
98	0.27			6.77		
99	0.17			4.30		
100	0.19			5.47		

NITRATE NITROGEN (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l
101	0.16			5.88		
102	0.46			3.73		
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.					
109	0.42	0.42	0.42	1.91	24.15	21.20
	Not loaded					
112	0.42	0.64	0.64	0.38	11.10	11.61
113	0.13	0.13	0.13	0.27	11.84	12.78
114	0.12	0.11	0.11	0.28	10.46	12.02
115	0.11	0.11	0.11	0.34	10.56	8.34
116	-	0.12	0.12	-	6.49	7.01
117	-	0.12	0.12	-	5.40	6.77
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.					
136		0.02	0.02		15.60	17.41
137		0.02	0.02		15.84	16.41
138		0.02	0.02		15.90	9.23
139		0.02	0.02		14.68	8.36
140		0.02	0.02		14.11	6.44
	Beds resting, pipe replacement.					
147		0.03	0.03		16.33	12.05
148		0.33	0.33		17.70	14.85
149		0.14	0.14		13.95	11.94
150		0.23	0.23		12.28	8.83
151	Beds resting, instrument problem.					
152		0.00	0.00		7.83	7.35
153		0.00	0.00		13.21	11.19
154		0.00	0.00		10.84	11.11
	Beds resting, instrument problem.					
157		0.00	0.00		8.76	7.54
158		0.02	0.02		5.37	6.30

TOTAL PROSPHORUS

Values shown are composite samples during the loading period for influents and single grab samples at 24 hours after loading for effleunts

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	6.70	4.70	6.50	0.31	0.51	0.56	95	89	91
2	4.40	5.30	5.00	0.36	0.40	0.43	92	92	91
3	5.20	5.20	5.50	0.72	0.27	0.67	86	95	91
4	5.60	5.30	5.40	0.44	0.44	0.55	92	92	90
5	5.10	5.00	5.00	0.45	0.36	0.52	91	93	90
6	6.40	6.00	5.70	0.56	0.54	0.75	91	91	87
7	7.90	6.30	7.10	0.85	0.94	0.98	89	85	86
8	8.20	6.90	8.10	1.05	1.40	1.10	87	80	86
9	8.20	8.20	7.40	1.20	1.50	1.50	85	82	80
10	8.20	9.20	7.20	1.10	1.60	1.40	87	83	81
11	-	-	-	-	-	-	-	-	-
12	-	4.70	4.70	-	2.70	3.20	-	43	32
13	5.60	4.40	5.60	2.70	3.10	5.10	52	30	9
14	8.70	9.00	9.60	4.40	2.50	4.20	50	72	56
15	8.90	7.20	7.20	3.00	2.50	4.20	66	65	42
16	6.60	5.90	6.60	3.20	3.30	5.50	52	44	17
17	6.70	4.70	7.60	2.50	3.10	6.50	63	34	15
18	8.70	6.20	7.60	3.60	3.40	5.80	59	45	24
19	9.20	6.30	7.90	4.00	3.40	6.00	57	46	24
20	10.30	7.00	9.60	4.40	2.50	4.20	49	72	56
21	8.90	7.20	7.00	3.00	2.50	4.20	66	65	42
22	6.60	6.60	8.80	3.70	4.40	6.40	46	33	27
23	5.70	5.80	7.80	4.10	2.90	6.50	28	50	17
	Rest and scarify.								
28	6.00	5.50	5.60	0.90	1.50	3.80	85	73	32
29	5.50	4.90	5.60	3.60	2.80	4.80	35	43	14
30	5.60	5.10	5.70	4.30	3.00	5.90	23	41	0
31	5.40	5.00	6.50	3.50	3.70	5.70	35	26	12
32	4.30	4.20	3.90	3.40	2.80	4.30	21	33	0
	Rest and scarify.								
37	5.30	5.40	5.00	3.50	3.20	2.90	34	41	42
38	Sampling manhole flooded.								
39	7.00	5.30	5.40	3.70	2.30	2.90	47	57	46
40	7.60	7.60	5.80	3.40	1.20	0.90	55	84	85
41	6.90	9.40	6.20	3.20	2.20	3.30	54	77	47
42	Sampling manhole flooded.								

TOTAL PHOSPHORUS (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
43	6.60	5.80	5.90	3.20	2.90	3.00	52	50	49
44	6.90	5.70	6.80	3.80	3.70	4.20	45	35	38
	Rest and scarify.								
50	7.95	8.40	9.25	0.20	0.006	-	98	99	-
51	6.55	8.90	8.75	0.80	0.28	0.28	88	97	97
52	9.70	7.95	17.20	-	1.30	0.52	-	84	93
	Resting caused by effluent pump malfunction.								
57	-	8.05	9.55	-	0.84	0.30	-	90	97
58	9.80	9.35	8.40	0.85	1.49	1.30	91	84	85
59	-	-	8.00	-	-	0.10	-	-	99
60	11.50	7.00	6.50	0.06	0.25	0.20	99	96	97
61	7.15	8.40	7.60	0.76	0.43	1.56	89	89	80
62	7.70	-	7.55	0.88	1.20	1.46	89	-	81
63	7.95	7.00	6.85	1.00	1.06	2.14	87	85	69
	Resting.								
66	7.15	6.90	7.25	1.35	1.56	1.68	81	77	77
67	6.95	7.35	6.45	1.41	1.40	1.03	80	81	84
68	-	-	-	-	-	-	-	-	-
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	11.65			0.63			95		
72	9.40			0.61			94		
73	6.30			0.70			89		
74	14.55			2.36			94		
75	9.65			1.64			83		
76	27.25			1.77			94		
77	19.91			1.49			93		
78	6.45			1.89			71		
	Resting.								
85	11.85			1.43			88		
86	14.65			1.59			89		
87	17.30			1.84			89		
88	4.25			0.45			89		
89	-			-			-		
90	4.55			0.43			91		
91	6.55			0.58			91		
92	4.25			0.15			97		
93	0.60			0.00			100		
94	3.35			0.39			88		
95	3.55			0.21			94		
96	3.70			0.20			95		
97	1.90			0.20			90		
98	10.70			0.26			98		
99	10.70			0.01			99		
100	17.00			0.02			100		
101	18.50			0.95			95		
102	18.60			0.23			99		

TOTAL PHOSPHORUS (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.								
109	12.80	12.80	12.80	1.20	0.56	0.53	91	96	95
	Not loaded								
112	12.20	9.15	9.15	3.16	0.87	0.56	74	91	94
113	8.40	8.40	8.40	2.64	0.95	0.99	67	89	88
114	9.20	8.30	8.30	2.83	0.95	0.63	69	89	92
115	5.95	5.95	5.95	2.12	0.48	0.33	64	92	95
116	-	10.44	10.44	-	0.50	0.39	-	95	96
117	-	9.70	9.70	-	0.32	0.60	-	97	94
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		4.60	4.60		0.15	0.17		97	96
137		5.20	5.20		0.12	0.14		98	97
138		5.80	5.80		0.12	0.20		98	97
139		5.80	5.80		0.10	0.15		98	97
140		4.95	4.95		0.08	0.12		99	98
	Beds resting, pipe replacement.								
147		6.20	6.20		0.13	0.15		98	98
148		4.95	4.95		0.22	0.24		96	95
149		4.85	4.85		0.10	0.30		98	94
150		5.40	5.40		0.14	0.14		97	97
151	Beds resting, instrument problem.								
152		2.05	2.05		0.51	0.20		75	90
153		4.90	4.90		0.13	0.19		98	96
154		5.75	5.75		0.10	0.18		98	97
	Beds resting, instrument problem.								
157		6.00	6.00		0.06	0.12		98	98
158		12.20	12.20		0.40	0.35		96	97

BIOCHEMICAL OXYGEN DEMAND, 5 day, 20°C

Values shown are composite samples during the loading period for influents and single grab samples at 24 hours after loading for effleunts

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	64.0	28.0	31.0	1.1	0.8	2.4	98	97	92
2	-	-	34.0	-	0.4	1.7	-	-	95
3	100.0	-	36.0	-	2.4	1.0	-	-	97
4	24.0	63.0	27.0	1.1	2.7	1.7	95	96	94
5	-	47.0	41.0	0.6	0.6	-	-	99	-
6	-	-	-	3.6	1.2	0.8	-	-	-
7	114.0	51.7	95.2	8.1	0.4	3.9	93	99	99
8	83.0	155.0	101.0	3.8	-	9.6	95	-	91
9	91.0	128.5	97.9	2.0	10.6	3.4	98	92	97
10	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-
12	-	130.9	87.7	-	13.0	9.6	-	90	89
13	167.3	85.7	150.9	4.9	10.2	8.2	97	88	95
14	163.2	185.6	109.7	4.3	13.7	8.1	97	93	93
15	121	107.7	141.3	6.4	12.7	10.8	95	88	92
16	118.5	110.7	111.6	13.2	14.7	3.9	89	87	96
17	90.7	78	73.6	14.8	12.8	9.4	84	84	87
18	97.5	67.8	85.2	11.4	10.9	3.9	88	84	95
19	97.2	66.3	102.0	7.5	12.0	12.9	92	82	87
20	117.0	63.0	105.3	5.1	12.9	15.2	96	80	86
21	123.0	135.0	108.0	3.9	14.4	15.7	97	89	86
22	108.0	97.5	114.0	9.3	33.6	17.8	91	66	84
23	96.0	81.0	78.0	-	15.6	17.7	-	81	77
	Rest and scarify.								
28	94.5	73.5	73.5	7.3	7.6	-	92	90	-
29	103.5	70.5	106.5	-	8.5	-	-	88	-
30	136.5	76.5	-	-	5.7	-	-	93	-
31	102.7	91.7	132.2	10.3	6.6	8.1	89	93	94
32	89.3	75.4	110.1	7.6	8.9	11.3	92	88	90
	Rest and scarify.								
37	111.3	141.6	155.4	10.2	10.1	15.0	91	93	90
38	Sampling manhole flooded.								
39	157.7	103.5	178.1	9.8	4.6	10.7	94	96	94
40	159.9	108.9	64.2	10.5	4.2	4.4	93	96	93
41	150.2	78.8	132.2	7.8	5.2	5.1	95	93	96
42	Sampling manhole flooded.								

BIOCHEMICAL OXYGEN DEMAND (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
43	75.3	84.3	99.2	3.7	7.1	7.5	95	92	92
44	147.3	132.3	123.2	5.6	10.3	10.9	96	92	91
	Rest and scarify.								
50	92.7	85.9	90.6	4.1	3.6	-	96	96	-
51	92.5	45.8	74.7	4.2	15.9	5.2	95	65	93
52	77.3	50.5	109.3	-	10.1	12.3	-	80	89
	Resting caused by effluent pump malfunction.								
57	-	78.6	104.8	-	9.8	16.8	-	88	84
58	71.8	73.1	87.6	5.8	15.6	9.7	92	79	89
59	214.4	117.0	103.2	7.4	-	10.4	97	-	90
60	117.1	113.3	-	8.5	19.2	13.1	93	88	-
61	159.8	-	126.4	10.8	14.8	15.6	93	-	88
62	126.6	111.5	108.7	12.5	13.6	15.8	90	88	86
63	-	-	-	-	-	-	-	-	-
	Resting.								
66	144.5	115.5	106.2	14.2	13.1	13.6	90	89	87
67	111.4	129.3	126.6	11.9	14.0	14.2	89	89	89
68	114.3	118.4	99.2	13.0	13.1	16.0	89	89	84
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	129.7			8.7			93		
72	103.1			6.3			94		
73	89.5			6.8			93		
74	92.2			11.0			88		
75	80.1			2.9			96		
76	96.3			5.1			95		
77	71.9			2.3			97		
78	64.7			2.6			96		
	Resting.								
85	66.7			8.7			96		
86	66.5			3.0			96		
87	42.8			1.6			96		
88	64.1			4.3			93		
89	-			-			-		
90	75.9			6.8			91		
91	70.7			4.5			94		
92	17.5			1.2			93		
93	46.2			2.5			95		
94	40.7			2.2			95		
95	64.1			1.7			97		
96	46.6			2.7			94		
97	52.3			3.2			94		
98	40.6			3.7			91		
99	75.5			9.0			88		
100	46.4			1.8			96		
101	52.1			1.7			97		
102	57.9			6.3			89		

BIOCHEMICAL OXYGEN DEMAND (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.								
109	-	-	-	-	-	-	-	-	-
	Not loaded								
112	-	-	-	-	-	-	-	-	-
113	127.7	127.7	127.7	9.7	2.3	7.4	92	98	94
114	74.2	125.6	125.6	13.1	2.1	2.5	82	98	98
115	135.5	135.5	135.5	5.0	1.5	1.3	96	99	99
116	-	99.2	99.2	-	6.2	4.3	-	94	96
117	-	102.1	102.1	-	8.5	6.2	-	92	94
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		77.7	77.7		4.2	1.7		95	98
137		29.8	29.8		1.1	0.7		96	98
138		27.4	27.4		0.9	0.9		97	97
139		48.1	48.1		0.4	0.6		99	99
140		42.7	42.7		1.0	1.3		98	97
	Beds resting, pipe replacement.								
147		78.8	78.8		1.1	0.6		99	99
148		68.9	68.9		0.4	0.3		99	99
149		65.2	65.2		0.1	0.0		100	100
150		53.9	53.9		0.2	0.1		100	100
151	Beds resting, instrument problem.								
152		75.4	75.4		0.5	0.6		99	99
153		57.7	57.7		0.3	0.2		100	100
154		79.4	79.4		0.4	0.4		99	99
	Beds resting, instrument problem.								
157		86.8	86.8		0.0	0.1		100	100
158		97.6	97.6		1.2	0.6		99	99

SUSPENDED SOLIDS

Values shown are composite samples during the loading period for influents and single grab samples at 7-24 hours after loading for effleunts

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
1	66.0	24.0	27.0	0.8	0.0	1.6	99	100	94
2	44.5	26.0	30.5	0.6	0.4	1.6	99	99	95
3	28.0	20.0	23.5	-	-	-	-	-	-
4	19.5	20.0	-	0.8	0.4	1.2	96	98	-
5	17.0	28.0	27.5	0.2	0.0	1.2	99	100	96
6	59.0	44.0	45.0	0.0	0.2	0.0	100	99	100
7	56.8	51.8	67.9	1.6	2.8	1.4	97	95	98
8	87.5	39.5	159.5	0.3	1.4	2.2	100	97	96
9	71.0	77.5	57.5	3.0	1.4	1.1	96	98	98
10	60.5	59.5	63.5	3.0	0.6	0.8	95	99	99
11	-	-	-	-	-	-	-	-	-
12	-	56.9	70.5	-	2.7	3.6	-	95	95
13	89.3	65.5	126.0	1.8	3.4	3.6	98	95	86
14	103.0	153.0	106.0	0.4	9.0	3.0	100	94	97
15	71.0	82.5	52.5	0.8	10.6	7.4	99	87	86
16	43.0	49.0	50.5	2.2	4.4	9.2	95	91	82
17	56.0	26.5	47.0	11.0	10.0	9.0	80	62	81
18	58.0	34.8	38.2	5.0	10.2	11.6	91	70	70
19	47.5	25.2	151.5	6.8	14.0	1.6	86	44	97
20	60.0	68.0	50.0	15.8	21.6	30.5	75	68	38
21	23.0	135.0	108.0	3.9	14.4	15.7	97	89	86
22	108.0	97.5	114.0	9.3	33.6	17.8	91	66	84
23	96.0	81.0	78.0	-	15.6	17.7	-	81	77
	Rest and scarify.								
28	94.5	73.5	73.5	7.3	7.6	-	92	90	-
29	55.0	52.0	48.0	29.0	17.3	32.0	47	67	33
30	35.5	40.0	47.0	15.7	15.5	24.0	56	61	49
31	41.5	50.0	49.5	17.5	18.7	24.0	58	63	52
32	45.0	42.5	54.5	25.5	20.2	23.2	43	53	57
	Rest and scarify.								
37	38.0	48.5	48.0	13.0	25.0	25.0	66	49	48
38	Sampling manhole flooded.								
39	56.0	60.0	59.5	16.2	8.2	22.2	71	86	63
40	47.0	39.5	55.0	23.7	14.2	13.5	50	64	76
41	65.5	52.5	39.5	21.0	13.2	8.7	68	75	78
42	Sampling manhole flooded.								

SUSPENDED SOLIDS (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
43	53.0	53.0	47.5	12.5	3.0	11.5	76	94	76
44	36.0	32.5	44.0	14.0	17.8	15.0	61	45	65
	Rest and scarify.								
50	66.0	48.5	52.0	2.0	0.0	-	97	100	-
51	49.5	47.5	38.5	24.3	11.0	7.5	51	77	81
52	41.5	54.0	144.5	-	16.0	14.3	-	70	68
	Resting caused by effluent pump malfunction.								
57	-	65.5	73.5	-	18.5	11.8	-	72	84
58	51.0	50.5	53.6	20.0	18.5	11.8	61	63	78
59	-	-	46.0	-	-	16.3	-	-	65
60	73.0	34.0	58.5	20.3	-	17.5	72	-	68
61	58.5	51.5	-	21.3	19.5	27.8	64	62	-
62	66.0	-	61.5	27.5	17.0	28.0	58	-	55
63	59.5	53.0	54.0	21.8	19.5	30.5	63	63	44
	Resting.								
66	65.5	57.0	58.0	32.5	20.8	39.3	50	64	32
67	76.0	60.5	63.5	29.5	29.3	34.5	61	52	46
68	69.0	48.0	62.0	17.5	16.8	31.5	74	65	49
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	74.5			25.8			65		
72	52.0			20.3			61		
73	47.0			18.8			60		
74	102.0			14.8			86		
75	58.5			20.3			65		
76	-			25.0			-		
77	38.0			9.0			76		
78	23.5			14.2			39		
	Resting.								
85	64.5			24.5			62		
86	58.0			18.0			69		
87	56.0			21.2			62		
88	32.5			17.3			47		
89	-			-			-		
90	89.5			13.0			86		
91	63.0			14.0			78		
92	28.5			1.2			96		
93	53.0			3.7			93		
94	37.5			6.0			84		
95	55.0			7.2			87		
96	55.0			7.2			87		
97	51.0			4.2			92		
98	52.0			4.5			91		
99	41.0			7.0			83		
100	65.0			7.0			89		
101	65.0			-			-		
102	49.0			7.0			86		

SUSPENDED SOLIDS (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.								
109	-	-	-	-	-	-	-	-	-
	Not loaded								
112	-	-	-	-	-	-	-	-	-
113	78.0	-	-	38.0	-	2.8	51	-	-
114	70.0	28.0	28.0	38.0	2.0	3.0	46	93	89
115	123.0	-	-	24.0	4.8	1.4	81	-	-
116	-	63.0	63.0	-	3.7	1.4	-	94	98
117	-	49.0	-	-	1.0	-	-	98	-
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		22.0	22.0		3.5	1.6		84	92
137		19.0	19.0		0.8	0.5		96	97
138		53.0	53.0		2.7	1.3		95	98
139		50.0	50.0		1.3	0.0		97	100
140		62.5	62.5		0.3	0.0		99	100
	Beds resting, pipe replacement.								
147		67.5	67.5		1.1	1.7		98	98
148		23.3	23.3		3.8	1.3		84	94
149		50.0	50.0		24.0	-		52	-
150		63.4	63.4		23.0	25.0		64	61
151	Beds resting, instrument problem.								
152		52.8	52.8		0.0	1.3		100	98
153		59.0	59.0		2.0	0.0		97	100
154		70.0	70.0		5.5	5.5		92	92
	Beds resting, instrument problem.								
157		54.0	54.0		0.0	0.0		100	100
158		66.0	66.0		0.0	0.0		100	100

pH

Values shown are composite samples during the loading period for influents and single grab samples at 7-24 hours after loading for effleunts

Week	In-1	In-2	In-3	Ef-1	Ef-2	Ef-3
1	-	-	-	-	-	-
2	6.60	6.60	6.90	6.70	6.80	6.60
3	6.95	6.90	6.60	6.80	7.00	6.70
4	6.90	6.90	6.90	6.80	6.80	6.60
5	7.05	7.05	6.60	6.80	6.60	6.60
6	7.00	7.20	7.10	6.80	7.10	6.60
7	7.50	7.90	7.00	7.70	7.10	7.00
8	6.90	6.00	7.10	8.60	7.00	7.00
9	-	6.80	7.00	7.10	6.90	6.40
10	6.80	7.15	6.73	6.98	7.08	6.79
11	-	-	-	-	-	-
12	-	7.04	7.12	-	6.75	6.71
13	6.92	7.10	6.92	6.75	6.88	6.62
14	6.98	6.90	7.28	6.85	6.63	6.70
15	7.29	7.28	7.58	6.92	6.95	6.69
16	7.35	7.15	7.15	6.80	6.85	6.83
17	6.74	6.80	6.75	8.02	6.61	6.83
18	6.73	6.83	7.43	6.59	6.76	6.56
19	6.79	7.42	6.94	6.77	6.62	6.68
20	6.75	6.89	6.94	6.82	6.64	6.76
21	6.75	6.63	7.10	6.72	6.73	6.68
22	6.70	7.08	6.37	7.20	7.30	7.11
23	7.01	7.04	7.04	7.03	6.95	6.75
	Rest and scarify.					
28	6.65	7.03	6.85	6.74	6.97	6.61
29	6.82	6.83	6.85	6.92	6.86	6.87
30	6.76	6.90	6.87	6.87	6.88	6.81
31	6.77	6.85	6.97	6.78	7.29	6.77
32	6.85	6.97	7.04	6.91	6.84	6.76
	Rest and scarify.					
37	6.62	6.80	7.00	6.52	6.63	6.50
38	Sampling manhole flooded.					
39	6.40	6.85	7.02	6.47	6.76	6.55
40	6.44	6.61	7.30	7.06	6.82	6.82
41	6.56	6.67	6.55	6.45	6.49	6.94
42	Sampling manhole flooded.					

pH (continued)

Week	In-1	In-2	In-3	Ef-1	Ef-2	Ef-3
43	6.59	6.88	7.01	6.49	6.92	6.89
44	6.48	6.71	6.97	6.62	6.56	6.89
	Rest and scarify.					
50	6.54	6.71	6.94	6.57	6.84	-
51	6.61	6.68	6.82	6.72	6.77	6.91
52	6.48	6.82	16.88	-	7.02	6.96
	Resting caused by effluent pump malfunction.					
57	-	6.76	6.92	-	6.97	6.89
58	6.52	6.64	6.95	6.71	6.86	7.01
59	-	-	6.82	-	-	6.94
60	6.52	6.72	6.89	6.68	6.87	6.94
61	6.61	6.78	6.82	6.79	6.90	6.96
62	6.71	6.69	6.91	6.82	6.89	7.02
63	6.56	6.82	6.92	6.74	6.89	7.05
	Resting.					
66	6.51	6.63	6.83	6.78	6.82	7.01
67	6.48	6.71	6.81	6.68	6.96	6.98
68	-	-	-	-	-	-
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.					
71	6.59			6.84		
72	6.51			6.78		
73	6.48			6.71		
74	6.61			6.89		
75	6.56			6.82		
76	6.48			6.68		
77	6.57			6.77		
78	6.46			6.69		
	Resting.					
85	6.54			6.79		
86	6.61			6.86		
87	6.59			6.87		
88	6.79			6.68		
89	-			-		
90	6.61			6.95		
91	7.07			6.55		
92	6.99			7.11		
93	7.21			6.88		
94	7.00			6.46		
95	6.97			6.50		
96	7.08			-		
97	7.35			6.98		
98	6.74			6.37		
99	6.96			6.69		
100	7.20			6.70		
101	7.08			-		
102	6.95			6.58		

pH (continued)

Week	In-1	In-2	In-3	Ef-1	Ef-2	Ef-3
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.					
109	-	-	-	-	-	-
	Not loaded					
112	-	-	-	-	-	-
113	6.64	-	-	7.03	-	7.00
114	6.74	6.76	6.76	7.29	7.03	7.47
115	7.23	-	-	6.94	6.78	6.88
116	-	6.61	6.61	-	5.98	6.05
117	-	6.63	6.63	-	6.07	-
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.					
136		6.90	6.90		6.00	6.24
137		6.74	6.74		6.44	6.65
138		7.00	7.00		6.54	6.61
139		6.48	6.48		6.42	6.50
140		6.89	6.89		6.27	6.45
	Beds resting, pipe replacement.					
147		6.75	6.75		6.38	6.47
148		7.08	7.08		6.69	6.45
149		7.05	7.05		7.49	6.70
150		7.00	7.00		6.87	7.17
151	Beds resting, instrument problem.					
152		6.80	6.80		6.80	7.00
153		6.60	6.60		6.80	7.00
154		6.70	6.70		6.80	6.80
	Beds resting, instrument problem.					
157		6.90	6.90		6.77	6.50
158		7.10	7.10		6.80	6.80

TOTAL ORGANIC CARBON

Values shown are composite samples during the loading period for influents and single grab samples at 7-24 hours after loading for effleunts. Testing procedure begun on week 41.

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
41	71	62	63	7.7	7.2	7.0	89	88	88
42	Sampling manhole flooded.								
43	65.6	61	78	7.7	7.1	37.5	88	88	51
44	72.5	73.3	64.2	7.3	7.5	8.4	90	90	87
	Rest and scarify.								
50	79.8	65.8	65.8	5.6	8.16	-	88	88	-
51	71.3	69.6	52.7	20.6	23.8	11.9	71	66	77
52	60.1	65.7	166.4	-	14.7	29.1	-	78	56
	Resting aused by effluent pump malfunction.								
57	-	78.6	105.2	-	17.9	30.9	-	74	71
58	61.4	59.9	61.9	6.9	14.2	9.5	89	76	85
59	-	-	87.6	-	-	11.7	-	-	87
60	132.7	72.9	76.8	12.7	16.7	11.3	90	77	85
61	71.3	71.3	53.9	9.2	20.7	13.4	88	71	75
62	98.9	-	75.2	37.2	24.0	17.1	62	-	77
63	-	52.2	-	-	14.4	19.3	-	72	-
	Resting.								
66	62.0	42.5	38.7	18.1	9.8	15.3	71	77	60
67	64.2	69.3	56.7	8.4	11.6	18.4	87	81	68
68	48.6	38.3	48.4	7.5	10.9	15.8	85	72	68
	Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.								
71	75.8			8.9			88		
72	56.9			6.4			66		
73	20.0			6.8			66		
74	60.8			6.6			89		
75	59.9			7.0			88		
76	50.7			5.5			89		
77	14.3			1.3			91		
78	33.1			5.8			83		
	Resting.								
85	60.4			5.7			91		
86	48.6			4.2			91		
87	44.0			3.6			92		
88	31.0			9.0			71		
89	-			-			-		

TOTAL ORGANIC CARBON (continued)

Week	In-1 mg/l	In-2 mg/l	In-3 mg/l	Ef-1 mg/l	Ef-2 mg/l	Ef-3 mg/l	%R-1	%R-2	%R-3
90	38.1			9.5			75		
91	43.3			7.2			83		
92	36.6			6.7			82		
93	34.7			6.8			80		
94	43.0			6.2			86		
95	49.5			7.8			84		
96	79.8			10.0			87		
97	76.7			10.0			87		
98	68.1			4.2			93		
99	55.6			5.1			91		
100	61.6			4.6			93		
101	67.6			6.8			90		
102	64.8			6.4			90		
	Influent values determined from sample beaker collection on the surface of the spray loaded bed 2. Effluent values based on single grab sample for each bed from week 109. Beds 2 and 3 manually sprinkler loaded from week 109.								
109	-	-	-	-	-	-	-	-	-
	Not loaded								
112	70.3	70.3	70.3	13.5	4.4	3.2	81	94	96
113	66.6	66.6	66.6	12.5	5.9	6.4	81	91	90
114	101.7	74.6	74.6	13.3	5.3	4.9	87	93	94
115	66.6	66.6	66.6	22.6	2.0	1.2	66	97	98
116	-	77.1	77.1	-	6.0	4.1	-	92	95
117	-	74.7	74.7	-	6.4	4.2	-	91	94
	Bed 1 discontinued and beds 2 and 3 computer, sprinkler loaded after resting period.								
136		32.8	32.8		7.4	4.2		78	87
137		27.3	27.3		4.1	3.5		85	87
138		63.7	63.7		3.5	3.3		95	95
139		62.5	62.5		0.7	2.5		99	96
140		59.5	59.5		1.0	2.7		98	96
	Beds resting, pipe replacement.								
147		42.7	42.7		3.9	6.0		91	86
148		30.6	30.6		2.5	5.1		92	83
149		10.0	10.0		2.8	5.3		72	47
150		21.6	21.6		1.8	6.5		92	70
151	Beds resting, instrument problem.								
152		11.6	11.6		6.2	4.9		47	58
153		30.8	30.8		4.0	4.4		87	86
154		85.4	85.4		3.8	4.6		96	95
	Beds resting, instrument problem.								
157		81.8	81.8		1.6	2.0		98	98
158		62.0	62.0		3.1	4.3		95	93

TOTAL AND FECAL COLIFORMS

TOTAL COLIFORM BACTERIA, 10^5 organisms/100 ml

Week	Bed	Influent	Effluent	% Removal
13	1	18.7	-	-
	2	38.6	1.5	96.1
	3	70.0	0.08	99.9
19	1	38.0	2.6	93.2
	2	20.0	1.4	93.0
	3	65.0	0.84	98.7
31	1	124.0	1.9	98.8
	2	74.0	2.5	96.6
	3	20.0	5.8	71.0
44	1	21.9	0.3	99.9
	2	116.0	5.0	95.7
	3	145.0	3.1	97.9
61	1	16.4	0.18	98.9
	2	57.2	0.75	98.7
	3	52.5	0.71	98.6
88	1	8.1	0.21	97.4
92	1	11.4	1.78	84.4
98	1	23.4	0.80	96.6

FECAL COLIFORM BACTERIA, 10^5 organisms/100ml

Week	Bed	Influent	Effluent	% Removal
13	1	4.9	0.21	95.7
	2	3.9	0.21	94.6
	3	19.0	0.34	98.2
19	1	9.6	0.75	92.2
	2	7.2	0.69	94.6
	3	18.0	0.22	98.8
31	1	11.8	0.75	93.7
	2	21.0	0.15	99.3
	3	35.3	1.43	96.0
44	1	4.3	0.10	97.7
	2	17.0	0.83	95.1
	3	22.6	0.72	96.8
61	1	7.7	0.31	96.0
	2	11.5	0.25	97.8
	3	7.3	0.38	94.8
88	1	8.1	0.21	97.4
92	1	11.4	1.78	84.4
98	1	23.4	0.80	96.6

INFILTRATION RATES

Week	Infiltration rate (cm/d) bed 1	bed 2	bed 3
1	>50	>50	>50
2	>50	>50	>50
3	>50	50	>50
4	>50	42	>50
5	>50	>50	>50
6	>50	>50	>50
7	>50	53	76
8	>50	>50	>50
9	>50	54	>50
10	>50	51	60
11	-	-	-
12	>50	38	23
13	>50	15	28
14	>50	18	10
15	>50	9	9
16	>50	22	10
17	20	14	9
18	22	14	11
19	19	15	9
20	10	15	8
21	11	12	6
22	13	7	7
23	13	12	10
	Rest and scarify.		
28	>50	24	30
29	24	24	30
30	24	24	37
31	18	18	31
32	18	18	31
	Rest and scarify.		
37	18	24	55
38	Sampling manhole flooded.		
39	12	18	55
40	18	24	43
41	24	31	55
42	Sampling manhole flooded.		
43	12	31	31
44	6	31	31
	Rest and scarify.		
50	>50	>50	46
51	20	30	28

(continued)

INFILTRATION RATES (continued)

Week	Infiltration rate (cm/d) bed 1	bed 2	bed 3
52	20	-	23
Resting caused by pump malfunction.			
57	-	13	30
58	49	15	24
59	-	-	20
60	12	11	15
61	10	9	26
62	15	12	18
63	12	12	15
Resting.			
66	-	7	-
67	8	10	17
68	6	9	19
Bed 1 rested, beds 2 and 3 taken off line to install sprinkler system.			
71	35		
72	7		
73	7		
74	6		
75	6		
76	7		
77	6		
78	6		
Rest and scarify			
85	>50		
86	>50		
87	43		
88	43		
89	>50		
90	36		
91	-		
92	30		
93	>50		
94	36		
95	34		
96	34		
97	34		
98	33		
99	32		
100	24		
101	11		
102	24		
Spray loaded beds were never flooded and measurements could not be made			